tion. In The Demand for Travel: Theory and Measurement (R.E. Quandt, ed.), Heath, Lexington, MA, 1970.
6. A.J. Blackburn. An Alternative Approach to Aggregation and Estimation in the Non-Linear Model. In The Demand for Travel: Theory and Measurement (R.E. Quandt, ed.), Heath, Lexington, MA, 1970.
7. A.G. Wilson. Entropy in Urban and Regional Modelling. Pion, London, England, 1970.
8. S. Cardell and F. Dunbar. Measuring the Impacts of Auto Downsizing. Transportation Research, Vol. 14, 1980.
9. Creighton, Hamburg, Inc. Transportation and Land Development: A Third Generation Model--Theory and Prototype. FHWA, 1969.
10. G.S. Cohen and others. Intercity Rail Patronage in the NYC-Buffalo Corridor: Models and Forecasts. New York State Department of Transportation, Albany, Rept. DOT-TSPD-DPB-50-77-7, May 1977.
11. BEA Regional Economic Projections. Bureau of Economic Analysis, U.S. Department of Commerce, public use tape.
12. BEA Regional Economic Projections: Magnetic Tape Users' Guide. Bureau of Economic Analysis, U.S. Department of Commerce, 1981.
13. 1977 National Travel Survey. Bureau of the Census, U.S. Department of Commerce, public use tape.
14. Dimensions of Airline Growth. Boeing Commercial Airplane Co., Seattle, March 1980.
15. FAA Aviation Forecasts: Fiscal Years 1981-1992. Federal Aviation Administration, U.S. Department of Transportation, Sept. 1980.
16. Outlook for Commercial Aircraft 1981-1995. McDonnell Douglas Corp., Long Beach, CA, July 1981.
17. D. Greene and others. Energy Savings Impacts of DOE's Conservation and Solar Programs. Oak Ridge National Laboratory, Oak Ridge, TN, Rept. ORNL/TM-7690-V2, May 1981.
18. Transportation Facts and Trends. Transportation Assn. of America, Washington, DC, 1981.
19. G. Kulp and others. Transportation Energy Conservation Data Books, 5th ed. Oak Ridge National Laboratory, Oak Ridge, TN, Rept. ORNL-5765, Nov. 1981.
20. Energy and Environmental Analysis, Inc. Vehicle Purchase and Use Data Matrices: NFO Gasoline Diary Panel. Office of Transportation Programs, U.S. Department of Energy, April 1981.
21. B. McNutt and R. Dulla. On Road Fuel Economy Trends and Impacts. Office of Conservation and Advanced Energy Systems Policy, U.S. Department of Energy, Feb. 1979.
22. A Look at NASA's Aircraft Energy Efficiency Program. U.S. General Accounting Office, July 1980.
23. R. Wilson. Options for Fueling America's Transportation. Presented at 60th Annual Meeting, TRB, 1981.
24. Aerospace Corporation. Examination of Commercial Aviation Operational Energy Conservation Strategies. Office of Transportation Programs, U.S. Department of Energy, El Segundo, CA, 1978.

Trends in Energy Use and Fuel Efficiency in the U.S. Commercial Airline Industry

JOEL B. SMITH

The relative contributions of four components of fuel-efficiency gain to total efficiency improvement in the U.S. commercial airline industry since the 1973 oil embargo are identified, and a determination is made as to whether the efficiency improvements after 1973 represent a change in behavior from past trends. Civil Aeronautics Board data are used. Total efficiency increases since 1973 are divided into four components of efficiency gain/load factor, mix, seating capacity, and technical and operating efficiency. The contribution of each component to the improvement of fuel efficiency is measured by estimating how much fuel would have been needed to deliver actual services in a particular year had the component under study been held at its 1973 level while the other components varied. The rise in load factors accounts for one-third of the efficiency gain from 1973 to 1980. The increase is due in part to deregulation of the industry. Seating capacity made the second largest contribution, followed by mix and technical and operating efficiency. To compare pre- and post-embargo trends, a trend of yearly seat miles per gallon for the pre-embargo period was derived and extrapolated into the post-1973 period. Actual seat miles per gallon does not rise above the historic trend until 1979. Industry behavior did not change its historic patterns until 1979. Apparently, that was the first time that fuel costs became a significant financial burden to the airlines. The industry response to the fuel price rise was hampered by the time lag involved in introducing new-model aircraft into the fleet.

The U.S. government is reducing its role in encouraging energy conservation to lessen America's dependence on imported oil. Since the government is relying more on the private sector to reduce U.S. dependence on foreign oil, it is important to know how effective the private sector has been in reducing fuel use. It will also be helpful to know what government programs have accomplished. The U.S. Department of Energy (DOE) is currently undertaking such an assessment of how much energy has been conserved by different parts of the private sector. As part of that analysis, this paper examines the record of the U.S. commercial airline industry in improving fuel efficiency from 1973 to 1980. The analysis should be of interest, certainly for what it reveals about the airline industry and how it responds to rising fuel prices but also because the time frame of the study includes both a period of government economic regulation (before October 24, 1978) and a period of deregulation (after October 24, 1978).

The basic record of the commercial airline industry since the 1973 Arab oil embargo is one of providing much more service than in the past with very little increase in fuel use. In 1973, the industry delivered 162 billion passenger miles; by 1980, that figure had increased 57 percent, to 254 billion passenger miles. Yet fuel use by the industry in 1979 was only 315 million gal, or 3 percent greater than its 1973 level of 9.565 billion gal.

Several questions are raised. The first is, How was the industry able to provide so much more service with virtually no increase in fuel consumption? Clearly, the industry has used fuel more efficiently in delivering service. More specifically, what were the components of the improved efficiency and how much fuel did they save? Second, was the increase in fuel efficiency spurred by rising oil prices or by a continuation of past trends? Finally, what can realistically be done in the future to even further improve the efficiency of delivering service?

This analysis will largely be devoted to answering the first question by identifying the components of the efficiency changes and how much fuel they saved. A base case for fuel use, assuming actual demand from 1973 to 1980 and no changes in the efficiency of service delivery since 1973, will be derived and compared with actual fuel use. The difference between the two cases is then divided into the efficiency components. The questions concerning trends and prospects for the future are also briefly discussed.

The analysis focuses only on the transportation of passengers and excludes helicopter service and flights devoted solely to transporting cargo. The analysis is of the industry as a whole, including domestic, international, local, Alaskan, and Hawaiian carriers. Commuter service is not included. The contributions to efficiency changes made by individual airline companies and manufacturers are not singled out.

BACKGROUND

The real cost of fuel used by the airlines has increased by nearly 400 percent since 1973. While fuel cost 12.8¢/gal in 1973, it cost, in 1973 dollars, 48.2¢/gal in 1980, or 89.4¢ in nominal dollars. Real fuel costs are shown in Figure 1 [data on fuel costs and ticket prices are taken from the Air Transport Association and the Council of Economic Advisors, and data on revenue passenger miles are taken from the Civil Aeronautics Board (CAB)]. With the price of fuel rising, more of the industry's resources were directed toward fuel payments. Based on data from the Air Transport Association, the airlines spent a much higher percentage of their resources on fuel in the latter part of the 1970s than in the mid-1970s, as indicated below:

Year	Portion Spent on Fuel (%)	Year	Portion Spent on Fuel (%)
1973	12.2	1977	20.6
1974	17.4	1978	20.1
1975	19.1	1979	24.8
1976	19.5	1980	30.7

The percentage of total operating costs devoted to fuel rose by 250 percent from 1973 to 1980--from 12.2 to 30.7 percent.

With the cost of a factor of production rising as quickly as the costs of jet fuel, it would follow that the total cost of production would rise. An indicator of the relative change in the total costs of production is the relative change in the price of travel. The price of travel is also of interest because that is what the consumer sees. Unlike the automobile sector, in which consumers are presented with the price of gasoline every time they fill their tank, in the airline sector the price of fuel is subsumed in the ticket price. The ticket price is composed of many factors, such as labor, capital, overhead, and, of course, fuel. Figure 1 is also a graph of the real price of air travel per mile flown from 1968 to 1980. The real price of air travel, which was falling prior to the oil embargo, rose in 1974 and then resumed its decline until 1980. In real terms, the average price of traveling 1 mile was 16 percent less in 1979 than it was in 1973. Only the sharp increases in oil prices in 1974 and 1980 caused real ticket prices to rise. In fact, the price of travel fell even in 1979, when the real cost of fuel rose by almost 9¢/gal.

Figure 1. Trends in economic operating factors.

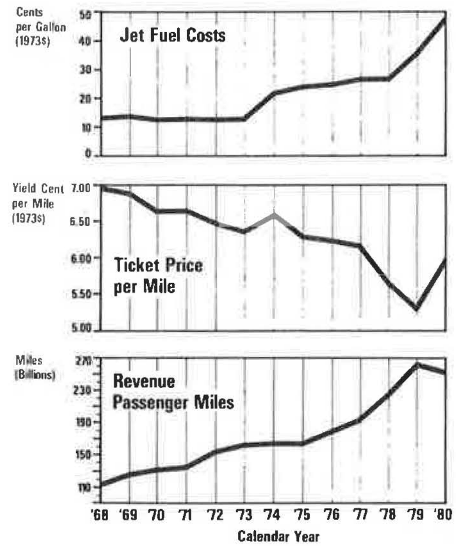


Table 1. Air carrier passenger traffic.

Year	Revenue Passenger Miles	Seat Miles	Load Factor
1967	98 746 641	174 818 524	56.5
1968	113 958 321	216 445 750	52.6
1969	125 414 212	250 845 906	50.0
1970	131 710 018	265 119 871	49.7
1971	135 651 780	279 869 172	48.5
1972	152 406 276	287 411 214	53.0
1973	161 957 307	310 597 107	52.1
1974	162 918 594	297 006 062	54.9
1975	162 810 057	303 006 043	53.7
1976	178 988 026	322 821 640	55.4
1977	193 218 837	345 566 005	55.9
1978	266 781 182	368 750 719	61.5
1979	261 979 214	416 144 986	63.0
1980	254 000 000	432 000 000	58.7

The drop in the real price of airline travel led to an increase in demand. Figure 1 and Table 1 present data on actual revenue passenger miles (RPMs) from 1968 to 1980 (one paying passenger traveling 1 mile constitutes 1 revenue passenger mile). With the exception of a leveling off in 1974-1975, the upward trend of the 1968-1972 period continued until 1979. Several factors led to the leveling off in demand in 1974 and 1975. The economy is always an important factor in determining airline travel demand. In those years, the United States underwent a deep recession. The price of travel rose in real terms in 1974, but dropped in 1975. The fuel allocation plan, discussed below, also served as a restraint on demand. With the economy improving and real ticket prices falling in 1976 and 1977, demand rose at an average annual rate of 6 percent. In 1978, the airline industry underwent a fundamental change: It was deregulated. The airlines were freed to drop inefficient routes, add more lucrative ones, and offer more competitive prices. The real price of travel fell at a more rapid rate than it had in the past. With the economy continuing to do well, demand rose at an even faster rate. From 1977 to 1979, revenue passenger miles rose at an annual rate of 10.7 percent. In 1980, however, the price of travel could no longer mask the increased price of fuel. The real cost of travel jumped while the economy cooled off. The result of these factors was that, for the first time in years, there was a significant decline in revenue passenger miles, with demand falling by 3.0 percent.

FUEL USE

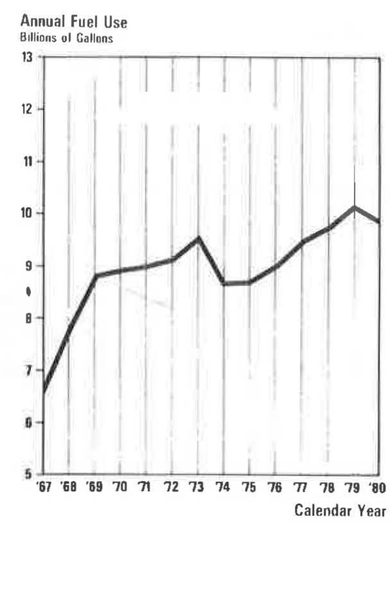
The year-to-year trend in fuel use does not parallel the trend in revenue passenger miles. Figure 2 shows fuel used by the airlines in delivering passenger service from 1967 to 1980. There was a monotonic rise in fuel use before the oil embargo. Following the embargo, the airlines were placed under a fuel allocation plan for 1974 and 1975. Basically, each airline was allocated 90 percent of the fuel it used in 1972. As shown in Figure 2, there was about a 10 percent drop in fuel use from 1973 to 1974. The 1975 level of fuel use was about the same as in 1974. With the restrictions lifted and the economy improving, fuel use by the industry began to grow in 1976. It continued to grow through 1979, surpassing the 1973 level of use in 1978. In 1980, fuel use declined, in part because of a curtailment in demand for passenger miles.

FUEL SAVINGS

The variable that best expresses the overall improvement in fuel efficiency by the airlines is the change in revenue passenger miles per gallon. By stating how many passenger miles were delivered for each gallon of fuel used, this variable measures how fuel efficient the airlines were in actually moving people. The following table gives revenue passenger miles and seat miles per gallon from 1967 to 1980:

Year	Revenue Passenger Miles per Gallon	Seat Miles per Gallon
1967	15.10	26.73
1968	14.62	27.78
1969	14.31	28.63
1970	14.80	29.79
1971	15.10	31.15
1972	16.69	31.48
1973	16.93	32.47
1974	18.82	34.32
1975	18.79	34.98
1976	19.78	35.67
1977	20.33	36.36
1978	23.36	37.83
1979	25.40	40.34
1980	25.73	43.68.

Figure 2. Actual fuel use for revenue passenger service only.



From 1973 to 1980, there was a 52 percent increase in the number of passenger miles delivered by each gallon of jet fuel. This variable is affected by the efficiency of service offered and by demand. If demand for air travel declines, the percentage of seats filled will probably drop, at least in the short run, and revenue passenger miles per gallon will decrease. If one did not want to consider the effects of demand changes, one could examine the efficiency of service offered.

Service offered is seat miles offered, and the fuel efficiency of service offered can be measured in seat miles per gallon, given in the table above. There is a steady rise in the efficiency of service offered from 1973 to 1978 and a large increase in efficiency in 1979 and 1980. The change in seat miles, however, is not quite as dramatic as the change in revenue passenger miles. In 1980, each gallon of jet fuel transported 35 percent more seat miles than did each gallon in 1973.

METHODOLOGY

A brief description of the methodology used in the analysis is given here. The following variables are used:

$$\text{Aircraft miles}_i = (\text{airborne hours}_i)\,(\text{airborne mph}_i)$$
$$\text{Seat miles}_i = (\text{airborne hours}_i)\,(\text{seats}_i)\,(\text{airborne mph}_i)$$
$$\text{Gallons/aircraft mile}_i = (\text{gallons/block hour})_i/\text{average block-to-block speed}_i$$
$$\text{Gallons/seat mile}_i = (\text{gallons/block hour})_i/[(\text{seats}_i)\,(\text{average block-to-block mph}_i)]$$
$$\text{Total gallons used} = \sum_{i=1}^{N} [(\text{gallons/block hour hour})_i/\text{average block-to-block mph}_i]\,(\text{airborne hours}_i)\,(\text{airborne mph}_i)$$

where i is model type.

Fuel-use equations used in the analysis are given below. For load factor,

$$\text{Fuel use} = (\text{fuel use}_b)\,(\text{load factor}_b/\text{load factor}_a) \quad (1)$$

where a = base year and b = year under analysis; for model mix,

$$\text{Fuel use} = \sum_{i=1}^{N} F_i \times TSM_b \times (\text{gallons/seat mile})_i \quad (2)$$

where i = model type, $F_i = SM_{ia}/TSM_a$, and TSM = total seat miles; for technical and operating efficiency,

$$\text{Fuel use} = \sum_{i=1}^{N} (\text{gallons/aircraft mile})_{ia} \times (\text{aircraft miles})_{ib} \quad (3)$$

and for seating capacity,

$$\text{Fuel use} = \sum_{i=1}^{N} (\text{gallons/seat mile})_{ia} \times (\text{seat miles})_{ib} - \sum_{i=1}^{N} (\text{gallons/aircraft mile})_{ia}\,(\text{seat miles})_{ib} \quad (4)$$

All of the data used in the analysis are from the CAB. Some of the figures cited (such as Figure 2 on actual fuel use) were also derived from CAB data.

Base Case

Basically, this analysis accounts for the changes in the fuel efficiency of delivered service that have happened since 1973. To measure the total change in the fuel efficiency of airline passenger service, a base case was constructed that assumed that actual demand was delivered with 1973 fuel efficiency. The difference between the base-case figures for fuel use and actual figures for fuel use is how much fuel was saved by improving the efficiency of delivery of service. The specific measure of efficiency of delivery of service is revenue passenger miles per gallon. That variable is held constant in the base case. For any percentage increase in actual revenue passenger miles traveled from one year to another, there is an equal percentage increase in the base case. Thus, the slope of the base case is the same as the slope of the revenue-passenger-miles line from 1973 to 1980.

Components of Efficiency Changes

The basic components of the improved efficiency of delivery of service are load factor, seating capacity, mix of aircraft, and technical and operating efficiency. Load factor is the percentage of available seats filled (not the number of passengers per aircraft). Seating capacity is the average seats per aircraft for each model type. Mix is the deployment of models to deliver service. Introducing new models, dropping old ones from use, and using existing models in greater or lesser proportion to others are examples of mix change. For the purpose of this analysis, mix is defined as the percentage of total seat miles flown by each aircraft model. Technical and operating efficiency is a measure of fuel use by the aircraft on an aircraft-mile basis. It includes such factors as the weight of the plane, the efficiency of the engines, cruise speed, angles of descent and ascent, altitudes, time spent circling, number of engines used while taxiing, congestion, maintenance, training, and many others.

Fuel-Use Analysis

The amount of fuel saved by improvements in each component in each year under study is estimated by calculating how much fuel would have been needed to deliver actual service in a particular year had the component under study remained at its 1973 level while all other components had their actual values. The difference between the derived figure and actual fuel use is the amount of fuel savings attributable to the change in the particular component. For example, the analysis of savings due to changes in the mix of aircraft involves holding the mix constant at its 1973 level while allowing the other components to vary as they actually did. The difference between fuel use with no mix change and actual fuel use is the savings due to mix change alone.

BASE CASE AND ACTUAL CASE

Figure 3 shows the base case along with actual fuel use for transporting revenue passengers. Most of the improvements in total efficiency are cumulative. An efficiency improvement made this year will save fuel next year. Total efficiency improvements increased roughly at a steady rate until 1977. In 1978 and 1979, there was a substantial increase in efficiency improvements. If 1973 efficiencies were delivered in 1975, an additional 952 million gal of fuel would have been needed. To have delivered the

Figure 3. Actual and base-case fuel use.

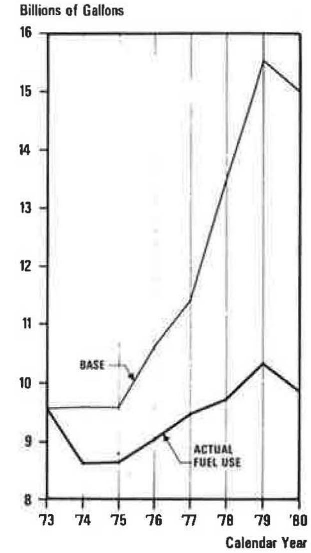
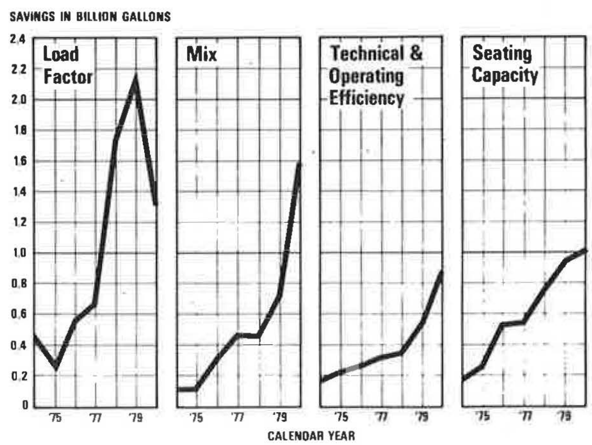


Figure 4. Fuel savings.



same amount of service in 1980 with 1973 revenue passenger miles per gallon would have required an additional 5.14 billion gal of fuel or another 335 000 bbl of fuel per day. From 1973 to 1980, improvements in the efficiency of delivery of service saved a cumulative total of 19.289 billion gal.

ANALYSIS AND RESULTS

Figure 4 shows the year-to-year fuel savings attributable to changes in each component. The numerical savings are presented in Table 2. This analysis is not intended to determine exactly the absolute amounts of fuel saved by each factor, since some of these factors are not completely independent of each other. Rather, the methodology provides a consistent basis on which to compare the relative amounts of fuel saved by each component. The absolute numbers should not be taken literally but can be used to compare efficiency components.

Load Factor

Total cumulative savings due to load-factor changes are estimated to be 7.2 billion gal. Of all of the estimates of savings, load factor may be the most

Table 2. Fuel savings.

Year	Fuel Use (billion gal)		Fuel Savings (billion gal)			
	Actual	Base Case	Load Factor	Mix	Technical and Operating Efficiency	Seating Capacity
1973	9.565	9.565	-	-	-	-
1974	8.655	9.622	0.465	0.107	0.174	0.187
1975	8.663	9.615	0.266	0.107	0.222	0.258
1976	9.051	10.571	0.573	0.316	0.270	0.522
1977	9.505	11.411	0.693	0.472	0.333	0.543
1978	9.748	13.393	1.759	0.463	0.341	0.765
1979	10.313	15.472	2.158	0.723	0.553	0.933
1980	9.871	15.011	1.330	1.417	0.876	1.193

misleading. Load factor is a function of seating capacity and number of passengers, not only number of passengers per aircraft. The savings stated in this analysis are based on the assumption that after 1973 the airlines would not have made better use of available seats. In other words, the percentage of seats filled would have remained constant. With increased seating capacity per aircraft, the number of passengers per aircraft would have risen with a constant load factor.

Although the change in load factor from 1973 to 1977 is only from 52.1 to 55.9 percent, the effect of the change on fuel efficiency is substantial. After 1977, savings due to load-factor changes grew at a much quicker rate. If load factor had been at its 1973 level in 1979, an additional 2 billion gal of fuel would have been needed to deliver the actual passenger miles.

Two factors had a major influence on the change in load factor from 1973 to 1980. The first is economic deregulation. With deregulation, the airlines were able to drop from service many of the inefficient routes that had low load factors. There is a marked change in load-factor levels following deregulation. The other factor that influences load factor is the economy. As the economy improved following the 1974-1975 recession, demand for service rose and the airlines were able to put more passengers in available seats. The 1980 recession and the increase in the real price of travel combined to lower demand and the load factor.

Seating Capacity

From 1973 to 1980, increased seating capacity saved a cumulative total of 4.2 billion gal of fuel. Perhaps the easiest way, in terms of cost, for the airlines to counter the effects of rising fuel and operating costs is to put more seats on individual aircraft. This can be accomplished by ordering more seats on new planes from the manufacturer or by replacing seats in older planes with a greater number of new seats (reseating). In 1973, the average Boeing 747 used in domestic flights had 328 seats. By 1980, the average 747 contained an additional 50 seats. From 1973 to 1980, the Boeing 727-200 logged more vehicle miles than any other model. The average 727-200 used by trunk lines for domestic purposes had 125 seats in 1973 and 133 seats in 1980. Local carriers using the same model jet had 147 seats in 1980. Of course, when seating capacity is increased, there is a cost to the passenger in terms of reduced average floor space per person. Adding more seats can add more weight to an aircraft, thereby increasing gallons per vehicle mile. Since additional seats allow more passengers to be placed on planes, the net effect of increased seating capacity on revenue passenger miles per gallon is positive.

Mix

After increased seating capacity, the next most important component of improved efficiency of delivery of service is mix. Mix is not just the number of different models in service but also the frequency of use. Mix changes saved an estimated cumulative total of 3.9 billion gal of fuel from 1973 to 1980.

In the 1970s, some very noticeable changes were made in the mix of aircraft models. Perhaps the most noticeable was the introduction of wide-body aircraft. The Boeing 747, the McDonnell Douglas DC-10 series, and the Lockheed L-1011 were first introduced in the early part of the decade. Within a couple of years, the wide bodies were transporting most of the passengers on long-distance trips. The DC-10, which logged 99 million aircraft miles in 1973 to provide passenger service, flew 167 million miles in 1980. The 1980 figure is an increase of 18 million miles over the previous year. Although wide bodies actually consume more gallons per vehicle mile, they are more fuel efficient because they transport more passenger miles per gallon. In 1980, the typical turbofan three-engine wide-body jet (DC-10 or L-1011) produced 51.2 seat miles/gal, whereas the typical turbofan three-engine regular-body jet (B-727) yielded 36.5 seat miles/gal.

With the wide bodies came new, more fuel-efficient jet engines such as the Pratt and Whitney JT9D, the General Electric CF6, and the Rolls Royce RB211, which superseded the much less fuel efficient JT3D, the standard engine on the B-707.

Another aspect of the mix change is the change in deployment of similar-sized aircraft with different efficiencies. The mix among 727-100s and 727-200s illustrates the point. The only major difference between the two models is that the 727-200 is a stretch version of the 727-100. Both are classified by CAB as three-engine, regular-body, turbofan aircraft. In 1973, the typical 727-100 had 96 seats available and delivered 27.4 seat miles/gal. Meanwhile, the 727-200 had 125 seats and got 31.9 seat miles/gal. In that year, the 727-100 flew 309 million aircraft miles and the 727-200 logged 306 million aircraft miles. Seven years later, the 727-100 had declined in its total use, flying 287 million aircraft miles, but the aircraft miles flown by the 727-200 jumped to 804 million miles. This mix change was a relative change, since the use of the less fuel-efficient aircraft was held constant while the use of the more fuel-efficient aircraft more than doubled.

The mix shift in 1980 had a larger impact on fuel efficiency than changes in any of the other components that year. The most significant change in mix from 1979 to 1980 was a major reduction in the use of inefficient four-engine, regular-body jets. Boeing 707s yielded 37.5 seat miles/gal in 1979 and flew 149 million miles. In 1980, their use was cut by 30 percent to 104 million miles. DC-8s, which delivered 96 million aircraft miles in 1979, were flown only 57 million miles in the following year, a 41 percent reduction. The DC-8-50, which flew 36 million miles in 1979 and only got 32.6 seat miles/gal, was dropped from use in 1980.

Technical and Operating Efficiency

The final component of improved efficiency in delivery of service is technical and operating efficiency. Although this aspect of fuel economy has probably received more attention in the media than the other components, its contribution to the change in efficiency of delivery of service has been relatively small. Improvements in the technical and operating efficiency of aircraft saved a cumulative total of 2.8 billion gal of fuel from 1973 to 1980.

Since, in this analysis, technical and operating efficiency is defined as fuel consumed from gate to gate, changes in anything from engines to cruise speeds to taxiing procedures affect the component. There have been a host of technical and operating improvements in recent years, especially in 1979 and 1980. Fuel is saved by using a steeper angle of descent in landing. Recently, the airlines have made an effort to reduce the weight of their planes. Lighter seats have been installed on many aircraft. Eastern Airlines scraped the paint off many of its jets (paint on a jet can weigh as much as 400 lb) and removed the 410-lb mechanical airstairs from the front of its 727s (1). Many jets now taxi with one or more engines shut down in order to save fuel. Maintenance procedures have been improved to make jets run more efficiently.

Summary of Components

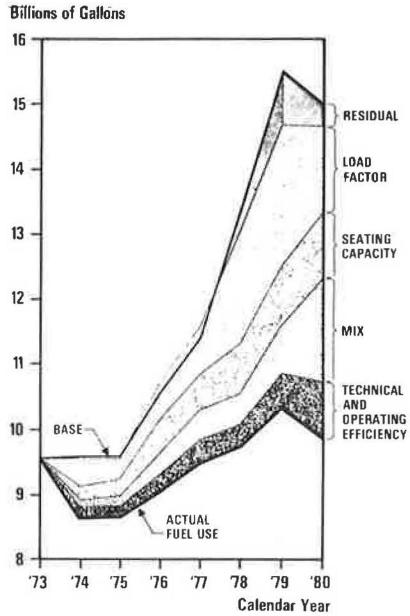
In Figure 5, the difference between the actual case and the base case is divided among the four components of improved efficiency. Of all the components, load factor appears to have had the largest effect on improved efficiency of service delivery. Load-factor improvements account for 42 percent of the improvement in efficiency in delivery of service from 1973 to 1979. Small changes in load factor make a relatively large difference in efficiency. Load factor rose from 52.1 percent in 1973 to 55.9 percent in 1977. Yet, in those years, the savings attributable to load factor are slightly larger than savings caused by changes in the other components.

Changes in seating capacity have the second-largest effect on efficiency in delivery of service. Increased seating capacity accounts for 22 percent of the total efficiency improvement from 1973 to 1980, mix changes contribute 20 percent, and changes in technical and operating efficiency account for 15 percent of efficiency improvements.

Residual Savings

As can be seen in Figure 5, in all of the years under study there is a residual of unexplained or overexplained efficiency savings. For most years, the residual is less than 10 percent of the difference between the base case and the actual case. There are at least two reasons for the existence of the residual. First, this "bottom-up" analysis should not explain the entire difference between the base case and the actual case. Second, the base case and the actual case are not from the same population. The actual case includes fuel used in charter service, whereas the base case only measures the percentage change in scheduled traffic. This would not pose too much of a problem if the ratio of scheduled to charter service remained constant over the period under study. In the late 1970s, the level of charter service delivered fell off dramatically. If the analysis were based solely on scheduled service, the base case would have the same shape it has now. However, the location of both lines and the shape of the actual case would be different. The slope of the actual case from 1976 to 1979 would be steeper. Such an adjustment would narrow the size of the residuals in 1978, 1979, and 1980.

Figure 5. Components of fuel efficiency improvements in U.S. commercial airline industry.



IMPACT OF OIL PRICE CHANGES ON FUEL EFFICIENCY

A substantial change took place in the fuel efficiency of service in the airline industry from 1973 to 1980. Yet the airline industry was not unique, since almost all industries will improve the efficiency of production over time. As can be seen in the earlier text table that gives 1967-1980 revenue passenger miles and seat miles per gallon, the efficiency of delivery of service in the airline industry was improving even before the oil embargo. The question here is whether the rise in the price of jet fuel caused the industry to improve efficiency at an even more rapid rate than it had in the past. To answer this question, a historic trend line of year-to-year changes in fleet seat miles per gallon in the pre-embargo period was derived and compared with actual seat miles per gallon for the post-embargo period. Seat miles per gallon was chosen as the unit of measurement because it includes all other components of efficiency change except load factor. Load factor is excluded, since it is directly affected by exogenous changes in demand for air travel--i.e., short-run economic cycles. The components that determine seat miles per gallon are mix, technical and operating efficiency, and seating capacity. Although mix, operating efficiency, and seating capacity can be changed relatively quickly, changes in those components have, in the past, not been a direct result of short-run economic cycles. Economic cycles in the pre-embargo period will have little effect on the trend line of seat miles per gallon developed for that period. Therefore, these are reasonable variables to include in the trend analysis.

The historical trend is derived from 1967-1972 seat miles per gallon. The results, for 1974-1980, are given below:

	Seat Miles per Gallon	
Year	Projection	Actual
1974	33.76	34.32
1975	34.76	34.98

	Seat Miles per Gallon	
Year	Projection	Actual
1976	35.76	35.67
1977	36.76	36.63
1978	37.76	37.83
1979	38.77	40.34
1980	39.77	43.68

From 1974 to 1978, the trend line almost exactly predicts actual seat miles per gallon. In 1979, actual seat miles per gallon exceed the historic trend by 4 percent. In 1980, the improvement over the historic trend is 10 percent. This would suggest that the airline industry made no improvement in efficiency over its historic trend until 1979.

This interpretation is supported by Figure 4, which shows the components of efficiency improvement. With the exception of load factor, there is a relatively steady increase in the amount of fuel "saved" by improvements in each component. These improvements do not appear to be sensitive to variations in oil prices until 1979. There are no sudden jumps in total efficiency in response to the fuel price rise in 1974, nor is there any leveling off of the rate of change in total efficiency as fuel prices leveled off in the mid-1970s (the jumps in technical and operating efficiency correspond with the oil price shocks of 1974, 1979, and 1980). In 1979, the savings from each component were significantly increased, and the combined effect (savings) was almost twice as much as the previous year-to-year changes.

Several factors explain this trend. One is that oil prices did not seriously affect the airline industry until 1979. The effect of oil price changes on total cost must be considered. Whereas the percentage of total operating expenses represented by fuel increased substantially from 1973 to 1974 (from 12.2 to 17.4 percent), as indicated in the first text table in this paper, there was a gradual change in the percentage from 1974 to 1979. This was reflected in the real price of travel, which increased slightly in 1974 but then fell for the next five years. Since the real price of travel is a rough measure of total costs, it can be concluded that, until 1979, increases in the price of fuel were made up for by economies in other factors of production.

By 1979, fuel prices again started to rise rapidly. This created two effects. First, fuel cost increased to 25 percent of total operating costs. This may have exceeded a "threshold" beyond which airline industry management had to deal with the problem quickly and effectively. Second, the cost of fuel rose too quickly to be offset by increased operating economies. This is reflected in the low airline profits in 1979 ($215 million compared with $1.36 billion in 1978 despite rising load factors and revenue passenger miles) and a rise in the real price of travel in 1980. In the face of these problems, the airlines may have made a more conscious effort to improve fuel efficiency.

Another factor that explains the relatively consistent trend is that the airlines were increasing the number of seat miles offered in both the pre-embargo and post-embargo periods and a side effect of this was to increase seat miles per gallon at a fairly constant rate. Before the oil embargo, the airlines introduced the wide-body jets in order, among other reasons, to offer more seats on longer routes. The B-747, DC-10, and L-1011 were introduced in 1970 and 1971 and by 1973 were playing a major role in providing air transportation. Since these planes deliver service more efficiently, the effect of this mix shift was to increase seat miles per gallon.

In the post-embargo period, there was a much smaller mix shift. From 1967 to 1971, 1288 jets were purchased by commercial airlines (including foreign flag carriers) from Boeing, the major manufacturer of commercial jets in the United States, but only 590 jets were purchased from 1973 to 1977. Following the 1974-1975 recession, the demand for air transportation began to rise. To service the rising demand, the airlines needed to expand their capacity. This could not be accomplished by bringing on new, larger models because no new models were available. Furthermore, the wide bodies had practically reached their saturation point in the market. To expand their capacity, the airlines increased the seating capacity on existing airplanes. This also increased seat miles per gallon and thus helped to keep the year-to-year change in the measure of fuel efficiency on its historic trend line.

In 1980, a substantial mix shift occurred. The major aspect of this shift was reducing the use of inefficient planes, such as the DC-8 and the B-707. A lower level of demand in 1980 than in the previous year made this possible. Had demand been rising, the airlines would have needed these inefficient planes more. If these aircraft had been used more extensively, the fleet fuel-efficiency improvement from 1979 to 1980 would not have been so dramatic. Thus, the flexibility of the airlines in making mix shifts is constrained by changes in the demand for air travel.

The long lag time between changes in economic conditions and the introduction of new-model aircraft in response to those changes may also help explain why efficiency did not improve at a rate above this historic trend. It takes a long time to design a new model and introduce it into the commercial airline fleet. Five years may elapse between the initial design of a new aircraft model and the beginning of production. It may take another three years of deliveries to accumulate enough planes to make a noticeable impact on fuel use. It could take eight years or more to bring on a new model to counter changing economic conditions.

New, more fuel-efficient planes will soon be introduced into the market. Within the next two years, Boeing will begin production of its 757s and 767s. These are highly fuel-efficient, two-engine, wide-body jets designed primarily for use on short- and medium-distance routes. Since the 747, DC-10, and L-1011 came out in the early 1970s, it may have been inevitable that new aircraft models would not be introduced until the early 1980s. Thus, even if it wanted to, the airline industry could not have introduced new, more fuel-efficient jets in the 1970s in response to rising fuel prices.

Taken together, these factors suggest a situation in which the airline industry (a) continued its historic increase in fuel efficiency until 1979, unaffected by fuel prices; (b) absorbed a significant portion of the rise in fuel prices until 1979, without having to raise the price of travel; and (c) was constrained by long-run forces in responding in the short run to quickly rising energy prices.

THE FUTURE

Tremendous potential for even further improving the efficiency of delivery of service still remains. Perhaps the most visible change to expect in the near future is the introduction of two-engine, wide-body jets for short- and medium-range service. Boeing estimates that its 757, which will seat between 178 and 223 passengers, will burn 35 percent less fuel per seat mile than current 727s, and its 767, which will seat between 211 and 289 passengers, will use 41 percent less fuel per seat mile than the 727. The 767 would deliver about 70 seat miles/

gal. The financial health of the airline industry and the level of interest rates will have a strong influence in determining when these new models will begin to be used by the airlines. There are many proposals for improvements in design. Among them are the use of new wings and winglets to reduce drag as aircraft move through the atmosphere. Retrofit improvements, which began in earnest within the past year, will probably become much more ambitious. Perhaps the most far reaching of the proposed changes is to replace the three JT8D engines on B-727s with two PW-2037 (formerly called JT10D) engines. This could reduce fuel use on 727s by about 30 percent. Many changes in operating procedures are being considered. One proposal is for jets that are held at the gate for more than 5 min beyond scheduled departure time to turn off their engines. There will most likely be greater use of simulators for training purposes.

There is no consensus on what will happen to load factor in the future. Many experts believe that load factor has peaked in the low to mid-60 percent range. They feel that further increasing load factors would result in scheduling problems and turning away many ticket buyers because of overbooked flights. Others believe that improvements in the economy will raise load factors into the mid-60 percent range. They maintain that the dropping of marginally profitable routes due to rising costs and the use of more efficient scheduling could raise load factors to more than 70 percent. The weight of opinion supports the former scenario. There is still great potential for increasing seating capacities. Of course, there are technical limits on seating capacity and psychological limits on how much crowding passengers will tolerate.

It is not clear what the relative weight of the components would be if the same analysis were done for 1980-1990. If load factor does exceed 70 percent, it will once again be the component that makes the largest contribution to efficiency improvements. If, as many experts predict, load factor does not rise, it will contribute very little to efficiency improvements. In 1980 alone, mix contributed more than the other individual factors to fuel-efficiency improvements. With the introduction of the 757 and 767, mix shifts could play an even larger role in improving fuel efficiency. As mentioned, there is also tremendous potential for improving seating capacity and technical and operating efficiency. It remains to be seen what the relative weight of the components will be.

CONCLUSIONS

Based on the analysis described in this paper, the following conclusions can be drawn:

1. In 1980, the U.S. commercial airline industry provided 57 percent more service than it did in 1973, using only 8 percent more fuel.
2. Load factor accounted for 37 percent of the efficiency improvement. That variable was followed in order of relative contribution by seating capacity (22 percent), mix (20 percent), and technical and operating efficiency (15 percent).
3. Most of the improvements in the fuel efficiency of delivery of service have come about through better use of existing aircraft. Adding more seats and using available seats more productively through higher load factors have been the most effective ways for the airline industry to meet rising demand with very little increase in fuel consumption.
4. Load-factor changes have been the most effective. Even small changes in load factor had a significant effect on the fuel efficiency of delivery of service. The major government policy decision affecting fuel use by commercial airlines was the deregulation of the industry. The jump in load factor and subsequent effects on fuel savings indicate that this decision had a positive impact on the efficiency of delivery of service.
5. The airline industry did not respond specifically to fuel price increases until the price shock of 1979. This is probably due to three factors: (a) fuel costs did not become a large burden for the industry until 1979, (b) the industry was apparently able to absorb fuel price increases until 1979 through economies in other factors of production, and (c) the short-term response of the industry to rising fuel prices was constrained by long-term forces.
6. In the next several years, there may be a change in the relative order of savings caused by changes in each component of efficiency. Load factor, the component that made the greatest contribution to efficiency improvement in the 1970s, may have reached its peak in 1979. Load factor may not rise in the 1980s and therefore will contribute little to efficiency improvements. Since new jets are soon to be introduced, mix may have a much larger role to play in improving the fuel efficiency of delivery of service in the 1980s.

ACKNOWLEDGMENT

This analysis could not have been done without the excellent data base provided by the CAB.

REFERENCE

1. R.E. Dallos. Fuel Costs Put Airlines on a Diet. Los Angeles Times, May 21, 1981.