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Technological Change in Transport: Panacea or Limited Prospect?

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TECHNOLOGICAL change in transport is as old as the invention of the wheel and its chronicle of ingenuity and usefulness is as distinguished as its longevity.[1] In recent centuries population growth has accentuated demands for the movement of people and goods, while the development of modern science has quickened the pace and extended the range of technological change in transport. In the current context the question of how much we can expect from this source of development assumes major significance.

The setting of social limits to technological change has long been the subject of passionate debate.[2] Optimists see technology as the engine of all progress, as a vehicle for the solution of most of our social problems, as a liberator of the individual bound too tightly in a complex society and as a fount of permanent prosperity—in short, as a panacea. Continuing support is found among those members of society who stand to benefit directly from technological change. A polar view sees technology as hostile and destructive. Technology is seen as an autonomous and unaccountable determinant of society which oppresses the individual, perverts our economics and threatens, ultimately, to destroy the natural environment. Always, this contrary view has support from those who suffer dislocation from technological change. A third position raises doubts that technology is worthy of special notice. Scholarly skeptics regard technological change as a long-established social fact that, in perspective, is not accelerating in the relative magnitude of its effects. Further, it is argued that we now have the means at our disposal to cope with its problems. It is a view that is comforting to those who find it restful to ignore the technological fact.

Economic thought about technological change presents us with a perplexing prospect. For a century and a half the mainstream of economic theory, almost without exception and despite an Industrial Revolution with its obvious impact, was preoccupied in the field of production economics with the economic allocation of existing resources to the neglect of changes in the production functions which technological change produces.[3] It was only in the last two or three decades that some redress occurred in economic thinking. Significant empirical work showed the strategic contribution to economic growth of new and superior production techniques used by better trained workers.[4] It was demonstrated that the introduction of new production methods which raise productivity — i.e., process innovation — offers economic gains through cost reduction which are fundamental and substantial. It should be noted that technological change often provides another benefit in the form of product innovation which may increase the quality of consumption. It was implied that these contributions more than offset costs arising from the misallocation of resources. This important insight required a revolution in economic thought to gain recognition. It would not be surprising if public policy towards technological change lags behind other fields of public policy.

If we turn to the conditions for technological innovation in terms of industrial market structures as incubators of such change we find a somewhat related but more specific debate. Here the question concerns the relative merits of monoploy and large firms versus competition and small firms.[5] Examination of theoretical debate and empirical studies directed to this issue leads one to a verdict of "not proven." Scherer concludes that:

> What is needed is a subtle blend of competition and monopoly, with more emphasis in general on the former than the latter and with the role of monopolistic elements diminishing when rich technological opportunities exist.[6]

The controversial nature of technological change reveals the complexity of the question under review. The primary purpose of this paper, however, is to sharpen the focus on the nature of technological change in transport, to develop some implications and to evaluate this source of change as a force in transport development.

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A TECHNOLOGICAL MIRACLE IN TRANSPORT?

If technological change in transport may be a panacea, examination of a major field of technological success in transport should be illuminating. Is the success such that it is capable of indefinite expansion or of generalization throughout transport? If not, are we to infer that the success is illusory? Or will the examination reveal a balancing of elements that act dynamically to produce a sequence of benefits and frustrations.

The choice for this test of the panacea hypothesis is commercial aircraft development and its application to airline use. Three criteria were used in this selection:

1. The presence of significant technological innovation.
2. The occurrence of a major traffic shift reasonably associated with changed technology.
3. A time-span for examination that is comparatively short and manageable.

Commercial aircraft development has been the locus of dramatic advances in power plants through the transition from piston engines to turbine power, in the form of turbo-props and jet engines, and in associated airframe development.[7] The traffic shift generated by the successful use of commercial aircraft of improved design is seen in the rise to dominance of passenger traffic of the air mode. For example, United States travel by public carrier in terms of passenger miles showed that the air, bus and rail modes were about even in 1955 but, by 1975, the edge of air over bus travel was about six-fold while rail passenger travel had experienced a serious decline to a level well below the bus figures.[8] In ocean traffic the "take-over" of passenger traffic by airliners from ships has been even more remarkable. Finally, this combination of "jet revolution" with a revolution in passenger traffic is observable over a period of two to three decades.

The technological change in aircraft which has commercial airline significance is revealed by the development of airliner carrying capacity. This capacity may be measured in seat-miles (or ton-miles) per year; the measure is the product of three components—number of seats per aircraft, speed and hours per year utilization.

It is clear that a substantial rate of progress was achieved with piston-engine aircraft. The DC-3 was an improvement on the Trimotor both because of a doubling in horse-power and also through radically better structural design. Again the DC-6B had four times the horse-power of the DC-3. Significantly its range was far superior (3,000 miles to 500 miles), of prime importance in the airline market. Turbo-prop airliners were introduced in the early 1950s and established new standards of quietness and comfort for passengers. The jets, led by the Boeing 707 and the Douglas DC-8, combined passenger comfort with size and greater speed to make dramatic gains in passenger seat-miles per year figures. All elements were positive—speed, size, utilization and comfort while the range of these aircraft made full exploitation of overseas and transcontinental markets practical. Utilization of the jets was double that of the DC-3. Airlines were given an ideal opportunity to build their traffic through the use of productive and attractive aircraft.

TABLE 1

SELECTED AIRLINER PERFORMANCE

Airliner	First Use	Cruise Speed	Seats	Pass. seat miles per year (millions)
Ford Trimotor 5-AT	1926	120	14	1.8
Douglas DC-3	1936	180	28	7.4
Lockheed L.049	1946	310	50	30.0
Douglas DC-6B	1951	315	66	52.0
Boeing 707-320	1959	545	144	250.0
Douglas DC-8-30	1959	535	142	245.0

Source: Derived from Davies, *A History of the World's Airlines.*

Canadian experience is revealed in a recent airline productivity study.[9] The metamorphosis of the airline fleets is shown in Tables 2 and 3 in terms of a shift from piston-engine aircraft to turbo-props and jets. In Level I operation, Air Canada had ceased to use piston-engine aircraft by 1964 while CP Air achieved an all-jet fleet by 1970. The significance of the establishment of regional air carrier policy by the Minister of Transport in 1966 is suggested by the fleet development statistics of the Level II airlines (the five regional carriers).

Productivity gains by the Level I airlines, on a total factor input basis, reached an annual rate of 4.5 per cent for the 1960-1976 period. However, the rate was much higher in the first decade when the major fleet changes were made. The 1960-1971 annual rate was 5.3 per cent compared to 2.7 per cent for the 1970-1976 period. For the Level II carriers it is interesting to note that total factor productivity declined somewhat in the 1960-1968 period but in the 1968-1976 period, with fleet modernization occurring, the annual rate was almost identical to that of the Level I carriers. While it must not be inferred that all of the productivity gains arose from the use of larger and faster aircraft, the impact of the "jet revolution" was very large. It is significant that, during the period under review, much of the improved productivity was translated into cost decreases and fare reductions.

TABLE 2

LEVEL I AIRLINES — PER CENT OF REVENUE HOURS BY AIRCRAFT TYPE

Year	Piston	Turboprop	Jet
1960	43.8	54.0	2.3
1965	37.2	10.3	31.8
1970	0.0	21.6	78.4
1975	0.0	0.0	100.0

Source: *Ibid.*, p. 148.

TABLE 3

LEVEL II AIRLINES — PER CENT OF TON-HOURS BY AIRCRAFT TYPE

Year	Piston	Turboprop	Jet
1960	91.1	8.9	0.0
1965	85.5	14.5	0.0
1970	19.5	27.0	53.6
1975	1.1	20.6	78.3

Source: *Ibid.*, pp. 166-168.

THE SUPERSONIC PROJECTS— A TECHNOLOGICAL GAMBLE

The break-through in commercial aviation that the jet airliners provided was based on aircraft engines and swept-wing airframe design. A lineal extension of the break-through was possible in two main directions, both of which would require yet more powerful engines—increased size of aircraft or higher speeds.

Development of aircraft of large size has proceeded with the Boeing 747. The thrust provided by its engines is about triple that of the initial Boeing 707 and the aircraft's output gain is in its carrying capacity—up to about 500 persons. Its speed is little better than that of the initial jets, while annual aircraft utilization remains about the same. This technological achievement, while impressive, follows a common pattern of aircraft evolution in a given design development phase. How far the size extension approach will go is speculative but airport problems and traffic density limitations in airline systems inhibit further enlargement of aircraft.[10]

A much more radical and risky approach to the technological extension of the jet revolution was to emphasize higher speed. Here designers were not in a position to extend speed in moderate increments as can be done with size. Aircraft efficiency problems dictated a jump in speed from the subsonic Mach 0.8, common to most jet airliners, to Mach 2.0 or higher. The aerodynamic efficiency of an aircraft drops sharply in the Mach 0.8 - 1.3 range but engine efficiency climbs with higher speeds. At Mach 2.0 overall efficiency approaches that found at Mach 0.8 and can be considered acceptable. However, as Mach numbers mount the material strength of metals weakens. Aluminum, the established metal for airframes, sharply deteriorates after Mach 1.7 and is in a seriously weakened condition by Mach 3.0. Furthermore, supersonic flight requires not only more powerful engines but poses very restrictive aerodynamic and structural problems in airframe design. However, the technical feasibility of sustained supersonic performance by large aircraft was apparent in the middle 1950s through B-58 bomber operation.

Three supersonic airliner projects were mounted. The British and French collaborated in the Concorde project, while the United States and Russia initiated their own projects. These projects are rich in technical, economic and political matters which space does not permit us to pursue.[11] Only the Concorde and the Russian TU-144 projects were carried to completion with rather similar aircraft designs in terms of configuration, size and speed.

The research and development costs of the projects were staggering. The Anglo-French Concorde required an expenditure of 1,096 million pounds while the United States SST project cost 983.4 million dollars, including 155.3 million dollars of termination costs. Equally impressive is the length of the research and development periods—1962-1975 for the Concorde and 1963-1972 for the terminated United States SST.[12] The Russian project had similar timing to that of the Concorde, with the TU-144 having the first test flight by a few months.

Despite the enormous commitment to technological change reflected in these figures, and the considerable talents of the design teams, limited results were to be achieved. The Concorde designers hoped to exploit known technology to the full by choosing a Mach number of 2.2, permitting the use of aluminum alloys, and a moderate size of aircraft. This policy, combined with aerodynamic restraints, restricted Concorde to a capacity of 120 to 130 seats. Supersonic airliners are relatively demanding on fuel use and the fuel weight requirement limited the range of the aircraft to trans-Atlantic length and restricted its sales potential. A further constraint on supersonic airliner saleability lies in their noise—take-off noise tends to be high but, more seriously, sonic boom is inherent in supersonic flight. Much effort was put into sales promotion of the Concorde and at one time a number of United States airlines had options on delivery positions to augment French and British commitments.[13] However, by the time the Concorde was ready for delivery only Air France and British Airways, contractually committed, bought aircraft.

What went wrong? In part the air transport market had shifted in the direction of a mass market for economical travel. Here the cost escalation of this already expensive project made Concorde uneconomic for most airlines. The limited seating capacity was unfavourable, but high load factors have helped the aircraft while in limited high-density route use. However, utilization problems are difficult to solve for Concorde as noise restrictions severely limit the aircraft's use and because its greatest strength — speed — creates the system utilization problems of shorter-range aircraft. A further penalty has been imposed by rising fuel costs to which supersonic aircraft are peculiarly vulnerable. Of the elements that combined to make subsonic jet airliners economical and attractive, only seed was present in the Concorde. It was not nearly enough.

The United States SST project followed a different pattern. The Americans elected to build a "second generation" supersonic airliner with a speed of Mach 2.7 and a capacity about twice that of the Concorde and the TU-144. Here the attempt was made to achieve more supportive economics by combining even greater speed with substantial size. The high Mach number required, however, use of titanium for the airframe. Use of this metal for a large aircraft required much research and dictated a longer development period than had been expected for the Concorde. Also, the design chosen was a swing-wing aircraft designed by Boeing (the 2007-100) for adaptability to subsonic as well as supersonic flight. The aircraft was designed for an all-up weight of over 600,000 pounds. As is common in new aircraft development, weight escalation occurred and the design weight reached an estimated 750,000 pounds by the start of 1968. This was unacceptable to the United States Government, which was providing most of the funding for the project. The design team was instructed to reduce the weight to 675,000 pounds but this was impossible. The problem lay in the weight of the swing-wing. After difficult negotiations Boeing was allowed to make a radical design change to save weight. The swing-wing was abandoned and the new design, the 2007-300, used a horizontal tail for the achievement of equivalent control of flight. The decision to allow this redesign was bound to be controversial as Boeing's 2007-100 design was selected on the basis of a competition with other manufacturers. However, this controversy was minor compared to that which was being mounted by environmentalists and other opponents of the SST. Finally, Congress withdrew support from the project despite a sympathetic Administration. It may be that the redesign delay was just enough to allow the project to be aborted.

Here, then, is a revealing sequel to the technological success of the "jet revolution." Limits, of a variety of types—technical, environmental, political, economic and system limitations—combined to confine this technological advance within narrow limits of operation.

THE TECHNOLOGICAL PROSPECT

Have airliners reached some sort of plateau in their technological development? The answer appears to be a qualified "no." Certainly the dramatic gains deriving from the application of increased engine power for more speed and size seems to have been exploited to a high degree. But it would be wrong to conclude that important progress will not be made. A change in objectives is, however, apparent and a new type of mobilization of scientific resources is occurring—one which draws on a wide range of scientific disciplines. Direct operating cost economy, especially in terms of fuel and maintenance cost savings, improved aircraft operating efficiency, environmental protection and safety are being sought in a variety of ways. No dominating technological innovation, comparable to the jet engine, appears to be in prospect.[14]

In the reasonably near future structural improvements should be important. Durability research is yielding good results in combining economical design practices with structural integrity. This work should economize maintenance and lessen maintenance delays for aircraft users. Structural efficiency or weight should be improved through the use of more conservative materials combined with advanced lightweight non-metallic materials. Further improvement can be achieved in improving the relationship between the structural aspect ratio of aircraft and the aerodynamic aspect ratio. In the electronics field major advances are being made through integrated digital systems. This area of advance is important as electronics cost almost half as much as the engines in modern jets. The promise is to cut maintenance costs in half while contributing more capacity, precision, reliability and lower initial cost. Engine fuel efficiency is receiving more emphasis through the development of high by-pass turbofans which give about 20 per cent better fuel efficiency than is given by first-generation turbofans.

Looking a little further ahead, the development of active controls is likely. These controls are used now in the form of flap load alleviators and vertical tail gust alleviators. The active controls of the future should allow much smaller tail size through the introduction of artificial stability and control use to lessen the strength and weight requirements of wings.

Also in prospect are fly-by-wire systems. These systems can eliminate the heavy control cables that connect the pilot's column to the control surfaces and thereby provide aircraft which carry more payload and are quieter, smaller and more economical in fuel use.

Of considerable importance is further structural improvement through the use of advanced composites in the field of materials. A major advance can be achieved through the application of advanced composite structure to the primary wing torque box. In a large aircraft, payload might be raised as much as 25 per cent through this advance. Use of advanced composites with graphite or boron fibres is in current application in military aircraft but costs and reliability for long-term use pose commercial problems.

In the field of aerodynamics, laminar flow control is the focus of active research. This approach involves the mechanical removal of the boundary layer so that laminar flow is maintained for practically the entire length of the wing airfoil section. Successful commercial development here can achieve a 25 per cent or better gain in cruise efficiency or in reduced fuel use. Technically this is possible but commercial application is difficult.

Further improvement is predictable in engine design. Here the emphasis will probably be on maintenance as well as on fuel economy.

It would be remiss not to highlight technological change which is directed to much improved management of airline flights to produce efficient takeoff, cruise, approach and landing operations. Use of additional electronics in the air and on the ground with air data links to a computerized central system can reduce the very substantial costs that airlines incur in inefficient system operation.

It would be encouraging if some dramatic innovation could be foreseen in fuels. Not only are fuel costs high but fuel weight and volume restricts the payload and range of aircraft. Liquid hydrogen offers considerable weight saving but its special equipment requirements in the form of pressurized, highly insulated storage tanks and fuel systems make its economics and commercial operation unattractive for the next couple of decades at least. Additionally, movement and storage of liquid hydrogen at airports is problematical and very costly. Nuclear power is a possibility offering a spectacular gain in unrefueled range. The problem here, however, lies in the weight of the reactor and it is unlikely that a design of sufficient lightness for aircraft application will be available in the next couple of decades. However, even without these radical technological changes, fuel economy gains should be substantial and seat-miles per gallon efficiency should improve even more in the next decade and a half.

SOME INFERENCES AND IMPLICATIONS

Our technological focus has been on aircraft and their application to airline use. What has emerged as a pattern?

1. Technological change is a continuing fact rather than a sporadic phenomenon.
2. Major powerplant innovation led to productivity gains through improved speed, size and utilization of aircraft. This was exploited successfully in airline use.
3. This innovative surge appears to have realized certain limits: (a) airline productivity gains have become harder to achieve. (b) gains in size have reached a reasonable range of extension. (c) speed extension has been sharply limited by technical, economic, operating and environmental considerations.
4. New technology is emerging on a wider scientific basis which offers practical and important gains in airline operating economy and safety.
5. The economic problems of aircraft development and airline operation continue to be substantial, and have even increased in complexity, despite a brilliant record of technological change.

It is note worthy that airlines continue to make their primary contribution as passenger carriers, although their freight traffic is developing, and to retain their emphasis on their comparative advantage in intermediate to long-range travel. Further, airport problems and operation in large urban environments have become more problematical. Continuing development of other modal solutions to transport problems will likely become more rather than less necessary.

It appears, on the basis of this examination, that technological change in transport is not a panacea. Nor is the prospect narrowly limited. Rather, technological change should be supportive of beneficial transport development on a continuing basis. In conclusion, a few points should be made:

1. Public policy and regulatory practice require further development to produce the best results from technological change. The necessary integration of technological change with other public interest considerations is still an insufficiency explored area of knowledge.
2. The distribution of the benefits of technological change among various groups—employees, shareholders, consumers, etc.—will probably become an increasingly difficult problem.
3. Technological change will operate in an increasingly complex environment and be subject to more demanding criteria in the evaluation of its claimed benefits.

Technological progress emerges from a broad foundation of scientific knowledge. It requires from us both realistic expectations about its potential and wise judgement in its application. Whatever we do it is important to remember that technological change, like all progress, is not a refundable item.

FOOTNOTES

1 For a definitive account, beginning c. 500 B.C., see C. Singer, E. J. Holmyard, A. R. Hall and T. I. Williams, eds., **A History of Technology**, Vol. I (Part II), Vol. II (Part IV), Vol. III (Part IV), Vol. IV (Part IV) and Vol. V (Part V), Oxford, at the Clarendon Press, 1954-1958.

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3 An important exception is the identification of innovation as the primary determinant of economic development in J. A. Schumpeter, **The Theory of Economic Development**, Harvard University Press, Cambridge, Massachusetts, 1934 (published in earlier form in German in 1911).

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6 **Ibid.**, p. 378.

7 For some useful treatments of aircraft development see P. W. Brooks, **The Modern Airliner**, Putnam, London, 1961; R. E. G. Davies, **A History of the World's Airlines**, Oxford University Press, London, 1964; R. E. Miller and D. Sawers, **The Technical Development of Modern Aviation**, Routledge and Kegan Paul, London, 1968 and A. Phillips, "Air Transportation in the United States," **Technological Change in Regulated Industries**, W. A. Capron, ed., The Brookings Institute, Washington, 1971, pp. 123-165.

8 J. E. Steiner, "Future Technology in Commercial Airplans," Paper presented to American Society of Civil Engineers, Philadelphia, September 30, 1976, p. 2.

9 P. S. Dhruvarajan and R. F. Harris et al., **A Productivity Study of the Canadian Airline Industry**, Canadian Transport Commission Research Branch, Ottawa, 1978.

10 For an interesting article on large-scale aircraft see D. Keith-Lucas, "The Prospects of 1,000-Passenger Aircraft," **Economics and Technical Change**, E. M. Hugh-Jones, ed., Basil Blackwell, Oxford, 1969, pp. 120-134.

11 For some fascinating information see D. Dwiggins, **The SST: Here It Comes Ready or Not**, Doubleday, Garden City, New York, 1968; J. Davis, **The Concorde Affair**, Leslie Frewin, England, 1969; J. Costello and T. Hughes, **The Concorde Conspiracy**, Charles Scribner's Sons, New York, 1976. For other references see C. Cocorda, "Selected Bibliography: The Supersonic Transport Aircraft," **Bulletin 7-E**, 1976, Institut du Transport Aerien, Paris.

12 J. Costello and T. Hughes, **The Concorde Affair**, p. 285.

13 By 1969, sixteen airlines had placed options for seventy-four aircraft.

14 For a more extended treatment see **NASA/University Conference on Aeronautics**, National Aeronautics and Space Administration, Washington, D.C., 1975; H. W. Withington, **Commercial Air Transportation Developments in the Next Three Decades**, Boeing, Renton, Washington, 1977; J. E. Steiner, **Future Technology in Commercial Airplanes**, 1976 and J. Rabary, "Looking Ahead to the Future Transport Aircraft," **Bulletin 44-E**, 1978, Institut du Transport Aerien, Paris.