7TH WCTR
SYDNEY AUSTRALIA
1 9 9 5

TOPIC 8
AVIATION AND AIRPORTS

DEREGULATION OF THE SOUTH AUSTRALIAN AVIATION MARKET

PAUL DULDIG
GPO Box 1045
Adelaide SA 5001
AUSTRALIA

Abstract

Intrastate aviation services (scheduled route passenger) were effectively deregulated in South Australia in 1979. As a result, over the next nineteen years the number of flights rose significantly whilst aircraft size reduced. This paper analyses the reasons for this. The analysis is based on development of a cost model, including operating cost and user costs.

INTRODUCTION

Aims of the paper

The purpose of this paper is to provide a model of the impact of the removal of entry controls from intrastate aviation in South Australia in 1979. Intrastate aviation markets provide a useful window on the effects of entry regulation as they have observable timetables, fares and passenger data, which aids comparative static analysis of market and regulatory performance. Entry (and exit) into the industry is relatively inexpensive and exhibits rapid turnover, which provides time series data for observation. The technology (aircraft) displays the characteristic of "lumpy" supply, which means that any analysis of market performance needs to take into account the user costs created when passengers can not leave at their preferred time, either because the flights do not leave when they want or the flights are fully booked.

The South Australian intrastate aviation market is defined as airlines carrying passengers on regular scheduled air services within South Australia. The South Australian intrastate aviation market serves small populations dispersed over large distances. The number of passengers using intrastate aviation services (one way ex Adelaide) was 2 300 per week in 1992, with population in the cities served (other than Adelaide) of only 117 000, and average distances travelled in the order of 250 kilometres.

Regulatory framework

Australian intrastate aviation markets have been subject to both Commonwealth and State Government economic regulation at times during the nineteen year period analysed in this paper (1973-1992). The Commonwealth Government's power to control aviation is restricted to matters concerned with "safety, regularity and efficiency, where regularity and efficiency have been interpreted as relating to safety and navigational aspects (BTCE 1988 p.3)". In 1978 the Commonwealth-based intrastate aviation regulatory system was scaled down to focus on operational matters (airworthiness, crewing, safety standards etc), in the light of concerns that the existing entry and service level regulations were beyond the power of the Commonwealth Government under the Australian Constitution. The Commonwealth Government retained its entry and service level regulation over interstate aviation by using its external affairs power under the Constitution to limit the import of aircraft used in interstate aviation.

As a result of the Commonwealth regulatory change in 1979, entry into the South Australian and Victorian intrastate aviation markets was effectively deregulated. New South Wales, Queensland, Western Australia, Tasmania and the Northern Territory retained their pre-existing state-based restricted entry regulations, although Queensland has since deregulated (1987), and New South Wales (1987) and Western Australia (1984) have since partially deregulated. The South Australian Government had a policy of "open skies", although the de-regulation decision could be described as "radical inaction" as it resulted from the State Government deciding *not* to impose a State-based regulatory system.

It is suggested that the Commonwealth Government regulatory regime has had a significant impact on the choice of aircraft used in South Australian intrastate aviation over the study period. After 1967, "third level" (commuter) operators could be granted an exemption under Air Navigation Regulation 203 to operate scheduled services without a full airline licence. Licences were not available for routes operated by existing "first" (interstate) and "second" (regional) level carriers, and because that left only very thin routes, the aircraft used were generally very small. This also probably distorted second level operators' choice of aircraft size towards larger aircraft as the *quid pro quo* of regulatory protection. After 1979, Commonwealth direct control over service levels in South Australia was removed, except that third level operators could not operate larger commuter aircraft over routes which included two or more trunk destinations (eg Adelaide—Mt Gambier—Melbourne), and after 1981, second level carriers were subject to capacity controls to protect the two domestic airlines. Both these residual capacity controls were removed on 30 October 1990.

As a result, prior to deregulation in 1979, "protected" airlines had incentives to use larger aircraft, whilst unprotected airlines were forced to use smaller aircraft. Given that the protected airlines had the majority of capacity and passengers, the effect of the regulatory scheme was to bias the system towards the use of larger aircraft and lower frequencies.

The fare regulation of incorporated regional airlines continued until the Independent Air Fares Committee (IAFC) was disbanded at the end of 1990, although prior to its demise the IAFC had mainly concentrated on interstate air fares and left the regional airlines largely unregulated.

The policy context

In the years since deregulation, there has been pressure on the South Australian Government to re-regulate the intrastate aviation market. The arguments in favour of re-regulation have focussed on the trend towards the use of smaller aircraft in the South Australian market, and the impacts of this on such factors as regional development, tourism and the possible flow through to higher fares from the use of less efficient smaller aircraft and their reliance on an increasingly costly fuel.

In 1980 Mr Bill Meeke, a local aircraft importer and general aviation operator, presented "A Report to the Premier Concerning Aviation in South Australia" in which he stated that "the system of air services in South Australia is *substantially* inferior to those of every other State" and that "there is no doubt that the development of South Australia is suffering at the mercy of inadequate air services" (Meeke 1980 pp. 1,2). Mr. Meeke favoured the use of turbo prop "mini airliners", the emerging aircraft technology at the time (around twenty seats), as opposed to the smaller piston engine aircraft (between five and nine seats) favoured by the existing commuter airlines. Mr Meeke argued for the increased service levels that could be offered by higher frequency, mid sized aircraft, both compared with the low frequency, large aircraft used by South Australia's then sole second level carrier, ANSETT Airlines of South Australia (ASA), and the high frequency but cramped small aircraft used by the existing third level airlines.

Mr. Meeke included in his report an industry press article (Brogden 1980) in which the General Manager of ASA was quoted as saying "there is no State control...South Australia being the one State which has no interest in local licensing or control of air transport (Brogden 1980 p.6)". The article continues "no legislation exists for that purpose and, despite protest, none looks like appearing in Adelaide. He ...[ASA]... even has a Cherokee competing with his Kangaroo Island service and on some routes he has more than one competitor flying a Navajo or something similar (Brogden 1980 pp. 6,7)".

In subsequent years other requests for re-regulation have been made and rejected by South Australian Governments. Prior to ASA ceasing operations in June 1986, there were representations made to the then South Australian Government for a degree of regulatory protection in order that ASA might re-equip to avoid closure. The author is personally aware of potential investors seeking monopoly rights on the major SA intrastate air routes in return for basing a domestic airline in Adelaide to compete with ANSETT and AUSTRALIAN post domestic deregulation in 1990.

The hypothesis

At the time of deregulation, South Australia had a comprehensive intrastate aviation network with ASA operating a fleet of turbo prop aircraft to six regional centres and a number of small airlines providing services to other regional centres. The most significant result of effective economic deregulation in South Australia in 1979 was a switch away from larger aircraft and a rise in frequencies offered over the system as a whole as displayed in Figure 1 for the four major routes ex Adelaide: Port Lincoln (PTL); Whyalla (WYA); Kingscote (KGC); and Mount Gambier (MGB). The second section discusses the trends in South Australian intrastate aviation in detail. The models developed in this paper will provide insights into why these trends have occurred.

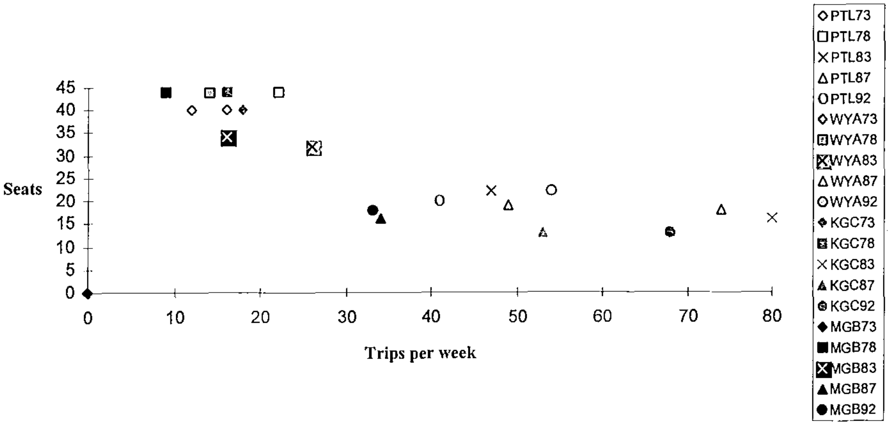

Figure 1 **Aircraft size and frequencies (top 4 South Australian routes, 1973-1992)**

The public policy question posed in this paper is whether the intrastate aviation market should be re-regulated to achieve lower operating costs and higher customer comfort from the consolidation of passengers on to large aircraft, or whether the deregulated market provides an improved outcome overall, because consumers value frequency relatively highly. However, this paper does not attempt to assess whether the removal of entry controls resulted in a social welfare optimum, but rather attempts to assess whether the effect of deregulation was an improvement in total cost. Clearly, demand side factors would need to be taken into account as well, for an analysis of social welfare. Nevertheless, the underlying approach in the paper is based on the welfare economics expectation that the removal of constraints on entry (in the absence of second best considerations) will lead to a higher level of social welfare.

The trade-off between aircraft size and frequency could be portrayed in Figure 2. If we assume that airlines' cost structures are such that the relative prices of extra aircraft size and extra frequency are fixed and positive, then the airlines' budget constraint could be represented by a downward sloping straight line as in Figure 2. If we also assume that consumers prefer higher frequencies and larger aircraft size, and that as aircraft size gets smaller they will demand increasingly greater frequencies to compensate, then the consumers' indifference curves will have the standard shape, as in Figure 2.

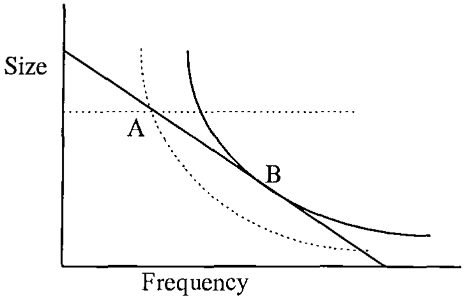

Figure 2 **Frequency size trade-off**

To model the effect on this trade-off from entry deregulation, it is assumed that the effect of the entry regulations was to impose a binding "minimum aircraft size" on the second level airline, ASA. In effect, ASA remained protected from direct competition by the use of larger aircraft. The assumed binding minimum aircraft size can be represented by the dashed horizontal line, resulting in a size frequency mix at point A under the restricted entry system.

If consumers have a stronger preference for greater frequency compared to greater aircraft size over the relevant range, the removal of the size constraint could be expected to lead to a lower aircraft size with greater frequency, which could be represented by point B. B is Pareto preferred to A, as it is on a higher indifference curve. If the change in regulatory system was not observed to lead to any change in the size/frequency mix, then the minimum aircraft size constraint under the regulated system can be seen as non-binding. The former case is consistent with the evidence presented in the second section.

The second section assesses the impact of the removal of entry controls in South Australia based on a *time series* of market performance trends. The third section builds a *producer cost* model of the South Australian intrastate aviation market, to provide insights into producer choice of aircraft size and frequency of trips supplied, whilst the fourth section overlays this producer cost model with an assessment of *user costs* to see how this changes the results of the trade-off. The fifth section provides some conclusions as to the nature of size/frequency trade-off in intrastate aviation markets.

IMPACT OF DEREGULATION IN SOUTH AUSTRALIA

Introduction

This section provides a time series analysis of the effects of economic deregulation in the South Australian intrastate aviation market, based on observations of market performance indicators developed by the author for the nineteen year period from 1973 to 1992.

Entry

The South Australian intrastate aviation market appears, despite high turnover, to be able to support at least ten commuter airlines. The names, owners and aircraft used often change, but the network coverage appears to have reached an equilibrium. The South Australian intrastate airlines that operated during the study period are displayed below in Table 1.

The number of operators rose after deregulation in 1979, and has stayed relatively stable at 10 to 12 operators over the subsequent period However, two significant underlying trends can be observed. Firstly, deregulation led to a rapid growth in the number of operators in South Australia. In 1981 there were 14 operators, three of which had commenced operations in 1980 and ceased operating in 1981. By 1983, some rationalisation had occurred, and between 1987 and 1992, the number of operators has remained stable. The second underlying trend was a marked change when South Australia's only second level operator, ASA ceased operating in 1986. This led to further route rationalisation, and enabled Kendell Airlines to expand into the major South Australian routes to become the leading operator with a significant presence in the two deregulated states (South Australia and Victoria).

There was also an expansion and subsequent rationalisation in the number of ports served, which rose rapidly after deregulation, mainly in the provision of indirect services to small communities which subsequently proved unprofitable. In 1983, ten extra ports had service compared with 1978, which was mainly the result of a network expansion by O'Connors and Commodore. Overall, the number of ports served in 1992 was greater than the number served in 1978, with three ports gaining a direct service, and one port gaining an indirect service (note that some ports have both).

Table 1 Ports served by intrastate aviation in South Australia, 1973-1992

Operator	Number of Ports served				
	1973	1978	1983	1987	1992
Ansett Airlines of SA [ceased June 1986]	5	6	5		
Albatross			1	1	1
Augusta Airways (Drennan/Far Northern) [from April 1983]			2	2	2
Air Kangaroo Island (Airtransit/Emu Air Charter)		2	3	4	3
Emu Airways [from Oct 1991]					1
Eyre (Charter/Commuter) [from Nov 1981]			2	2	2
Intercity (Williams) [ceased Jan 1981]		1			
Kendell				10	8
Lincoln [from Sept 1987]				1	1
Lloyd				4	
O'Connors Air Services [from July 1980]			16	1	1
Opal [ceased August 1986]	1	1	3		
Rossair [ceased June 1986]			4		
Skytour Air Charters [from July 1980, ceased June 1981, recomm Oct 1982, ceased July 1983]			1		
State Air (Commodore) [ceased 1986]			6		
Southern Australia (Sunstate Mildura/Murray Valley)		1	1	1	1
Transregional (PAGAS) [ceased May 1983]	2	4	4		
Whyalla Airlines					4
Wudinna (Air Central Eyre) [ceased July 1987]				2	
Total Number of Operators	3	6	12	10	10
Ports served with direct flights	8	12	18	16	15
Ports served with indirect flights	0	7	17	7	8
Total Number of Ports served	8	17	27	19	19

Service levels

Service levels have improved over the study period. Table 2 below outlines the changes in service levels in the SA intrastate aviation market over the nineteen year study period. The number of seats offered direct from Adelaide to SA communities rose by 19% in the five years after deregulation and another 9.5% in the four years after that. The five years from 1987 to 1992 have seen a drop in seats offered of 4%, which is still some 25% higher than immediately prior to deregulation. Passenger numbers also increased by 9% in the five years after deregulation, but subsequently dipped 2.1% below the pre-deregulation levels by 1987. Passenger numbers had picked up by 1992 to be 3.0% above the pre-deregulation levels. Load factors fell throughout the period as increases in passenger numbers failed to keep pace with numbers of seats offered. Average distance travelled fluctuated somewhat throughout the period, but was 9% lower in 1992 compared with 1978.

Table 2 Service levels in the South Australian intrastate aviation market, 1973-1992

Indicator	1973	1978	1983	1987	1992
Seats per year—direct	123,219	182,728	218,264	239,048	228,961
Passengers per year	87,100	117,007	127,707	114,539	120,485
Load Factors (%)	71	68	59	53	53
Average distance (km)	766	269	234	287	245

Fares

Fares rose throughout the period in nominal and real terms, on both weighted average and fare per kilometre bases as displayed below in Table 3.

Table 3 Fares in the South Australian intrastate aviation market, 1973-1992

Indicator	1973	1978	1983	1987	1992
Weighted Ave. fare ($)	13.26	29.10	53.84	77.49	103.02
Weighted Ave. fare ($1973)	13.26	15.56	18.03	19.63	19.53
Fare/km (cents)	6.13	13.15	23.89	30.35	41.35
Fare/km (cents 1973)	6.13	7.03	8.00	7.69	7.84

Real air fares per route kilometre rose by 24% over the period 1978 to 1992 (compared with a real rise in the then Bureau of Transport's "short haul air route index" of 56% over the period 1978 to 1987).

Service quality

The two main dimensions of service quality discussed in this paper are aircraft size (seats) and trip frequencies. Aircraft size (seats) fell dramatically after deregulation and has stayed stable since. The number of trips per week direct ex Adelaide rose rapidly after deregulation and peaked in 1987 at some 2.2 times the 1978 level as shown below in Table 4. Note the rapid increase in indirect flights between 1978 and 1983, as the market expanded post deregulation, with some ports receiving service for the first time. Many of these ports subsequently lost services as the market rationalised after 1983, but the number of trips in total stayed some 1.6 times higher in 1992 than it was in 1978.

Table 4 Service quality in the South Australian intrastate aviation market, 1973-1992

Indicator	1973	1978	1983	1987	1992
Average Aircraft Size	29	26	17	15	16
Trips per week—direct	83	137	273	306	276
Trips per week—indirect		61	134	64	50
Trips per week—total	83	198	407	370	326

The marked change in reduced aircraft size and increased frequencies is the key finding of this section. The next sections develop a generalised cost model of the South Australian intrastate aviation market, to attempt to evaluate whether the significant changes in "quality" evidenced here were an improvement in total cost.

PRODUCER COST

Introduction

In order to understand why the removal of entry controls on South Australian intrastate aviation in 1979 caused such a marked shift towards smaller aircraft operating at higher frequencies, it is important to understand producers' cost functions, which underlie the "budget constraint" of the size/frequency trade-off depicted in Figure 2. To this end, this section develops a cost model of intrastate aviation in South Australia, based on unit costs from the Bureau of Transport and Communications Economics "AEROCOST" model, and a network model developed by the author based on market conditions observed in South Australian intrastate aviation.

Definitions

The model developed in the following sections is based on a simplified version of the South Australian intrastate aviation market. The following variables are defined:

H	length of day, = T_e-T_b (hours)
Y	flying days in a year (days)
L	maximum acceptable load factor (%)
TV	money value of time ($)
R	routes, destination ex Adelaide: r,s,t,u
P_r	passengers on route r per day, one way (INT)
D_r	distance of route r one way ex Adelaide (kms)
SU_r	set up cost of route r ($)
A	aircraft: a,b,c,d,e
Z_a	passenger capacity of aircraft a (seats)
C_a	cruising speed of aircraft a (km/h)
X_a	fixed time (loading, taxiing, take-off) per flight of aircraft a (hours)
TO_a	fixed costs of aircraft a per flight ($)
K_a	cost per kilometre (cruising) of aircraft a ($)
O_a	purchase price of aircraft a ($millions)
DP_a	depreciation period for aircraft a (years)
T_{ra}	minimum return flight time on route r for aircraft a (hours)
F_{ra}	return flights per day on route r of aircraft a (INT)
S_{ra}	spare flying time for each aircraft a on route r (hours)
U_{ra}	spare flying time for the under utilised aircraft a on route r (hours)
N_{ra}	number of aircraft a used on route r (INT)

Producers are modelled as cost minimisers, as the model has no revenue dimension. It is assumed that all passengers return on the same day, or alternatively, one way passenger flows are exactly matched (mirrored) by return flows, with demand for flights uniformly distributed throughout the day. Airlines provide just enough capacity in a day to fully clear the number of passengers P_{ra}, at a load factor for each aircraft not exceeding L. Airlines own and allocate to each route just enough aircraft to provide the capacity as defined above. The frequency of flights offered by producers for cost minimising operations on each route is modelled as the expected number of passengers on the route divided by the maximum acceptable load factor (a constant), all divided by the seating capacity of the aircraft in question. If the aircraft are operating at maximum acceptable load factor, then any additional passenger will be provided with an extra fight.

$$F_{ra} = \{ (P_r / L) / Z_a \}_{INT} + 1 \qquad \text{when } \{ (P_r / L) / Z_a \} \text{ not INT} \qquad (1)$$

$$\textit{or} \qquad = \{ (P_r / L) / Z_a \} \qquad \text{when } \{ (P_r / L) / Z_a \} \text{ is INT}$$

The minimum return flight time is modelled as twice the time taken for a one way flight, which is calculated as the fixed time (for loading, taxiing, and take-off), plus the distance divided by the cruising speed of the aircraft.

$$T_{ra} = 2 * \{X_a + (D_r / C_a) \} \qquad (2)$$

The number of aircraft that are needed for cost minimising operation on each route is defined as the number of return flights per day divided by the time taken for a return flight on each route.

$$N_{ra} = (F_{ra} / T_{ra}) + 1 \qquad \text{when } F_{ra} / T_{ra} \text{ not INT} \qquad (3)$$

$$\textit{or} \qquad = (F_{ra} / T_{ra}) \qquad \text{when } F_{ar} / T_{ra} \text{ is INT}$$

There are two producer costs to be modelled in this analysis. Firstly, operating costs on a route are made up of fixed take off costs per flight, cruising costs and set up costs for route establishment (such as advertising).

$$\text{Operating cost per pax} = \qquad [F_{ra} * \{ TO_a + (K_a * D_r) \} + SU_r] / P_r \qquad (4)$$

Secondly, ownership costs need to be calculated in order that the model can have a network dimension, rather than just focussing on individual routes. Ownership costs are calculated by multiplying the number of aircraft owned, by the purchase price of the aircraft amortised over the number of flying days in a year.

$$\text{Ownership costs per pax} = \quad [\, N_{ra} * \{\, O_a\, (\, DP_a * Y\,)\, \} * 1{,}000{,}000] \,/\, P_r \qquad (5)$$

Estimating operating costs

Operating costs of five aircraft used by regional airlines (see Table 5) were derived from the AEROCOST model developed by the Bureau of Transport and Communications Economics (BTCE), which provides costs per flight over different distances and passengers numbers based on BTCE assumptions about capital costs, crewing requirements and costs, and fuel and maintenance costs. The AEROCOST model "calculates the direct operating costs for aircraft on a particular route by simulating operation of the aircraft over one year" (BTCE 1990 p2). Unit costs and operational variables are based on BTCE observations, derived where appropriate from aircraft manufacturer specifications. Analysis of the model showed that cost per kilometre for each aircraft is a convex function of distance travelled, whilst costs per flight do not vary with numbers of passengers. The first assumption is a reasonable approximation, given the fixed ownership and take-off costs of a flight.

Estimating total producer costs

The main cost and operating characteristics of the five aircraft types are displayed in Table 5.

Table 5 Cost and operating characteristics of five main aircraft types

	Units	Piper	Metro	DHC6	SHT330	SHT360
Z_a	seats	9	20	25	30	36
TO_a	$	145.57	431.36	438.01	645.12	722.83
K_a	$/km	0.8309	1.7404	1.9634	2.0224	1.9833
C_a	km/h	335	460	250	295	320
X_a	mins	42	36	36	39	36
O_a	$m	$0.3	$5.0	$0.4	$1.1	$2.8
DP_a	years	5	15	3	5	10

Additional assumptions:

H length of day, = T_e-T_b (10 hours / day)
Y flying days in a year (300 days / year)
L maximum acceptable load factor for all r (85 %)

In order to simplify the analysis, the costing was based on the four major South Australian routes as shown in Table 6. When these data are used to calculate operating and ownership costs of operating each aircraft across each route individually the results are displayed in Table 7.

Table 6 Major South Australian routes

	Units	Pt Lincoln (PTL)	Whyalla (WYA)	Kingscote (KGC)	Mt Gambier (MGB)
1987	annual pax	33334	23982	20416	13997
P_r	daily pax	111	80	68	47
D_r	km	243	230	126	371

Table 7 Minimum cost aircraft on an individual route basis

Cost per pax	PTL	WYA	KGC	MGB
Operating cost	$43.37	$44.77	$33.12	$60.67
	Sht360	Sht360	Piper	Sht330
Ownership cost	$8.00	$10.13	$6.54	$15.94
	DHC6	Piper	DHC6	Shts330
Total producer cost	$55.91	$56.29	$41.95	$76.61
	Piper	DHC6	Piper	Shts330

This analysis serves to show that when individual routes are analysed individually (ie not as a network), the larger aircraft are the minimum operating and ownership cost choice on three of the four routes. However, from the perspective of total producer cost, the smallest aircraft is minimum cost on two of the four routes.

In order to model these routes as a network, the following assumptions were made. Firstly, it is assumed that operators would prefer to operate the same aircraft type across the network, which results in five discrete scenarios, one for each aircraft type. Secondly, it is assumed that aircraft can be shared across routes within the one network. Thirdly, airlines economise on the ownership of aircraft consistent with providing enough capacity on each route.

Producer costs per day of using each aircraft type if they were each used exclusively across the network are displayed below in Table 8. The key results are that, from the network point of view, the use of the largest aircraft is minimum operating cost, the use of the middle sized aircraft is minimum ownership cost, whilst the use of the smallest aircraft is minimum total producer cost.

Table 8 Network producer costs

Costs per day	Piper	Metro	DHC6	Shts330	Shts360
Operating	$14,345	$15,972	$15,290	$15,615	$14,191
Ownership	$2,800	$5,556	$2,667	$3,667	$3,733
(Aircraft saved)	2	1	1	1	1
Total Producer	$17,145	$21,528	$17,957	$19,281	$17,925

The next section develops a user cost model to complete the model of generalised cost.

USER COST

Frequency delay cost

Frequency delay cost is the time cost incurred by consumers, who have to reschedule their departures away from their preferred departure times, because aircraft departures are not continuous. The greater the frequency the lower the frequency delay cost, hence the smaller the aircraft being operated the smaller the frequency delay costs. In this section, frequency delay costs are estimated based on an address model of the intrastate aviation market. The address model approach can be applied to the airline market in that departure times can be viewed as "addresses" for consumption of the service, with consumers evenly distributed over all such possible addresses. Consumers incur differential levels of disutility depending on where they "reside" in relation to the "address" of the nearest aircraft departure time. A consumer whose preferred departure time falls exactly on the time of departure of a flight incurs no frequency delay cost. A consumer whose preferred time of departure falls one unit of time away from an actual departure incurs one unit of frequency delay cost.

Frequency delay cost to a particular passenger is the cost to them of a unit (hour, minute) of frequency delay multiplied by the frequency delay experienced. It is assumed that the cost of a unit of frequency delay is a positive constant function of time delay incurred, based on an opportunity cost of time of $20 hour (Director-General of Transport 1991). It is also assumed that consumers have the same unit cost of frequency delay regardless of whether the actual rescheduling of departure time away from preferred departure time involves forward or backward rescheduling.

Frequency delay will depend on assumptions about how many departures there might be in a day, and what spacing (if any) between flights will be adopted throughout the day. It is assumed that the number of departures required in a day is a function of the aircraft size chosen, and the size of the market in terms of passengers per day. Firms are assumed not to provide more flights on a route than the minimum needed to carry the daily passenger load. It is of course possible for an airline to operate more flights than this in order to provide frequency benefits to users, but we assume firms are myopic in this regard.

The subsequent discussion develops the frequency delay functions of consumers with respect to different assumptions about the number of departures in a day. Should only one departure occur per day, an address model approach to scheduling would mean that the departure would be provided exactly in the middle of daylight hours. Should two departures occur, they will be provided one quarter of the day into the daylight hours, and one quarter of the day before the end of daylight hours. Should three departures occur, they will be provided one sixth of the way in to the day, in the middle of the day, and one sixth before the end of the day. The maximum delay experienced in each case is the "headway" divided by two, where the headway is the time between flights, and the minimum is zero. Therefore, because preferred departure times are assumed to be uniformly distributed through the day, the frequency delay is the headway divided by four, which is equal to the number of hours in the day, divided by the number of trips in the day divided by four. This generalises to the case of *n* flights per day.

$$\text{Frequency delay cost} = ((H / F_r) / 4) * TV \tag{6}$$

This formula was used to calculate frequency delay cost per passenger for five different sized regional aircraft (Z_a = 9, 20, 25, 30 & 36) across a range of passenger numbers experienced on intrastate aviation routes (P_r from 20 to 100). Frequency delay costs obviously do not vary over different distances, or for different passenger loads on the aircraft, but clearly the more frequent flights of the smaller aircraft yield lower frequency delay costs.

These results can be compared with the model specified by Douglas and Miller (1974) which used simulation modelling and Markov analysis, in which frequency delay is related to flight frequency in a logarithmic function. Over all passenger numbers, and for all aircraft, the Douglas and Miller formulation results in higher frequency delay costs per passenger.

$$\text{Frequency delay cost (D\&M)} = 92 * (F_r^{-0.456}) * TV \tag{7}$$

For comparison, the "first principles" model results were recalculated raised to the power 0.5, and this yielded results quite similar to the Douglas and Miller specification. Note that this first principles specification only differs from Douglas and Miller in that the power of F_r is -0.5 not -0.456, and that the coefficient of the function is replaced by the square root of (H/4). The costs estimated by this specification are slightly lower than for Douglas and Miller.

$$\text{Frequency delay cost} = ((H / F_r) / 4)^{0.5} * TV \tag{8}$$

As a result, the first principles specification raised to the power 0.5 appears to be a very good approximation of the Douglas and Miller results. The implications of this are interesting. The first principles specification makes a number of limiting assumptions, the most important being that users' preferences are evenly distributed throughout the daylight hours. Clearly this is not realistic. Douglas and Miller's specification is not limited by this particular assumption, hence the result of this simple comparison of Frequency delay specifications suggests that the first principles specification raised to the power 0.5 can be used to arrive at reasonably realistic estimates of frequency delay costs.

Stochastic delay costs

Stochastic delay cost is the time cost incurred by consumers, who are unable to catch a chosen flight because the aircraft is full. Frequency delay occurs when a flight does not leave at the users' preferred time, whilst stochastic delay occurs when the most preferred flight is full. Even though all passengers will "get a ride" in any one day because the number of flights provided will assure this, a passenger may have to take a flight at a time which is not the time closest to their preferred departure time. Stochastic delay costs are calculated using the same assumptions as for frequency delay costs except that it is assumed that consumers arrive at the airport (or perhaps ring up to book) in order to travel at any one of the scheduled departure times, and can not reschedule backwards.

Expected stochastic delay cost equals the cost of unit of stochastic delay multiplied by the expected stochastic delay. It is assumed that the unit cost of stochastic delay is the same as that for frequency delay, and that assumptions about the distribution of actual departure times are the same as for the frequency delay case. Expected stochastic delay will equal the chance of the flight being full multiplied by the expected delay if it is full. For the case of one flight per day, a passenger that can not catch the flight must wait until the next flight, which is in the middle of the next day, that is an average wait of 24 hours. For the case of two flights per day, a passenger who misses the first flight must wait until the second flight, which is half a day away. A passenger who misses the last flight must wait overnight until the first flight of the next day, which is half a day away plus all of the night. Hence the stochastic delay is the average of the delay experiences of the two cases, as a consumer may arrive to catch any one of the flights on a particular day. Algebraic manipulation yields the result that the stochastic delay is equal to the sum of the number of hours in the day and night, divided by the number of flights in the day. This generalises to the case of *n* flights per day.

The chance of the flight being full will depend on the size of the aircraft being used and the number of passengers who wish to travel per day. One simple assumption would be that the chance of the flight being full is equal to the average route load factor, which is equal to the number of passengers per day on the route divided by the aircraft seats provided to the route per day. However, this leads to the unrealistic result that stochastic delay costs increase linearly with the number of passengers, but clearly it could be expected to rise exponentially as the aircraft becomes full. Douglas and Miller (1974) base their stochastic delay specification on, *inter alia*, the concept of "relative capacity", which is a function of the difference between total aircraft capacity (Flights * Seats) and the number of passengers. This is adopted in the initial first principles specification as the denominator of the "load factor" variable which acts as a proxy for the probability of missing a flight.

$$\text{Expected stochastic delay} = (P_r / (Z_a * F_{ra} - P_r)) * (H / F_{ra}) * TV \qquad (9)$$

This formula was used to calculate expected stochastic delay costs for the five aircraft sizes defined as for frequency delay, across the same range of passenger numbers. Under this formulation stochastic delay costs tend to dominate frequency delay costs, even for very low numbers of passengers using relatively large aircraft, which seems the opposite of what we might expect. Also, stochastic delay costs rise steadily in an almost linear relationship with the number of passengers, which seems unrealistic.

Douglas and Miller (1974) estimate stochastic delay functions using simulation modelling and Markov analysis, based on expected fluctuations in demand (which may cause the flight to be full), the "relative capacity" of the route and the average interval between flights.

$$\text{Expected stochastic delay (D \& M)} = .455 * (Y^{-0.645}) * (X^{-1.79}) * (H / F_r) * TV \qquad (10)$$

Y = ratio of mean passengers per flight to its standard deviation

X = relative capacity which equals ratio of (mean aircraft capacity-mean passengers per flight) to the standard deviation of mean passengers per flight

The expected stochastic delay costs under this specification are very low up to the point when only one or two more passengers can be taken, at which point stochastic delay costs rise very steeply. This accords with our expectation that costs would not rise in a linear fashion.

The first principles specification was modified in two ways, to attempt to approximate the shape of the Douglas and Miller functions. Firstly, the numerator of the "relative capacity" measure was set equal to one, or in other words raised to a power of zero, and secondly, the "relative capacity" measure was raised to a power of two.

$$\text{Expected stochastic delay (zero power)} = (1 / (Z_a * F_{ra} - P_r)) * (H / F_{ra}) * TV \qquad (11)$$

$$\text{Expected stochastic delay (squared)} = (1 / (Z_a * F_{ra} - P_r))^2 * (H / F_{ra}) * TV \qquad (12)$$

These much simpler specifications provide remarkably close approximations to the Douglas and Miller specification. The probability component of these simple specifications is based on a relative capacity measure which is simply the inverse of the absolute number of seats left as yet unbooked over the whole day. The implications of this are that these very simple model can provide a very realistic approximation of stochastic delay costs, despite the limiting assumptions made. The squared specification is used in the total cost curves that follow.

Note that because this specification of stochastic delay is based on the absolute number of seats as yet unbooked on any day, stochastic delay costs are largely unrelated to the size of the aircraft on any particular route, *except when the limit of number of seats is approached.* There are less of these limits (which are lumpy and depend on aircraft size relative to number of passengers) in the case of larger aircraft, whereas the smaller say 9 seater aircraft reach these limits every extra 8 or 9 passengers. Hence the stochastic delay effect tends to favour the use of larger aircraft.

User costs

Using the frequency and stochastic delay cost functions developed in this section, user costs were calculated for each route on an individual basis, as shown in Table 9.

Table 9 **Minimum cost aircraft on an individual route basis**

Cost per pax	PTL	WYA	KGC	MGB
Frequency cost	$8.16	$9.53	$10.54	$11.95
	Piper	Piper	Piper	Piper
Stochastic cost	$0.02	$0.03	$0.04	$0.08
	DHC6	Sht330	Sht360	DHC6
Total user cost	$8.19	$9.58	$10.67	$12.05
	Piper	Piper	Piper	Piper

This shows that on an individual route basis, the smaller aircraft leads to minimum frequency cost per passenger. However, stochastic delay costs are relatively small, so minimum user cost is dominated by frequency delay effects, which supports the use of smaller aircraft. Similar results are achieved on a network basis, as shown in Table 10.

Table 10 **User costs of using each aircraft type exclusively across the network**

Cost per day	Piper	Metro	DHC6	Sht330	Sht360
Frequency	$2,927	$4,360	$4,599	$5,091	$5,469
Stochastic	$19.65	$50.16	$18.36	$38.08	$21.02
Total User	$2,947	$4,410	$4,617	$5,129	$5,490

THE SIZE/FREQUENCY TRADE-OFF

The model developed for this paper is based on the preceding derivation of total generalised cost which includes the producer's operating and ownership costs of the aircraft, and consumers' time related costs of aircraft not flying frequently enough (frequency delay), and/or aircraft being full (stochastic delay). The research, using the model, focuses on the trade-offs inherent in the choice between the operation of large aircraft infrequently and small aircraft frequently on a particular route, and whether or not the nature of that trade changes as distances travelled and passengers numbers increase. Producer (operating and ownership) costs and user (frequency delay and stochastic delay) costs were summed to provide estimates of total generalised costs per passenger and per day across the network. The results are displayed in Tables 11 and 12 below.

Table 11 Minimum generalised cost aircraft on an individual route basis

Cost per pax	PTL	WYA	KGC	MGB
Generalised cost	$64.10 Piper	$66.59 Piper	$52.62 Piper	$98.51 Piper

Table 12 Generalised costs of using each aircraft type exclusively across the network

Cost per day	Piper	Metro	DHC6	Sht330	Sht360
Generalised cost	$20,092	$25,938	$22,574	$24,410	$23,415

Under the assumptions made in developing this model, for shorter trips, the impact of frequency delay costs appears to outweigh the reductions in operating costs associated with the use of larger aircraft. The smallest aircraft size flying more frequently (with lower frequency delay costs and periodically higher stochastic delay costs) dominates the larger aircraft flying less frequently (with low operating costs). In summary, there are operating and ownership cost benefits from the use of larger aircraft, but smaller aircraft are preferred from a total generalised cost perspective, as they have relatively lower frequency delay costs. While stochastic delay effects favour the use of larger aircraft, the impacts are relatively unimportant.

This provides some evidence that short routes with low passenger numbers might be better served by small aircraft, as opposed to the "technical efficiency" view which favours the use of regulation to encourage the use of larger aircraft. In addition, it provides some insight into the reasons why the market in South Australia moved towards smaller aircraft offering higher frequencies after effective deregulation, as the regulated market forced the use of larger jet aircraft, but this did not result in minimum generalised cost. On this basis, it is suggested that the move towards smaller aircraft and higher frequencies was an improvement in the cost efficiency of the market, from both the producer and the user perspective.

ACKNOWLEDGMENTS

The assistance of Dr. Christopher Findlay and Mr. Nigel Daw is greatly appreciated. All errors of fact and interpretation remain the author's responsibility.

REFERENCES

Brogden, S. (1980) On the Second Level. *Aircraft*, April, 1-7.

Bureau of Transport and Communications Economics (1988) *Intrastate Aviation: Performance and Prospects, Occasional Paper 95*. AGPS Canberra.

Bureau of Transport and Communications Economics (1990) *AEROCOST—An Aircraft Costing Model*. AGPS, Canberra.

Bureau of Transport and Communications Economics (1991) *A New Era in Australian Aviation, Report 73*. AGPS, Canberra.

Director General of Transport (1991) *Project Evaluation Guidelines.* Government of South Australia, Adelaide.

Douglas, G.W. and J.C. Miller III (1974) *Economic regulation of domestic air transport: Theory and Policy.* The Brookings Institution, Washington, D.C.

Duldig, P. and C. Findlay (1990) Deregulation in a low density market: the case of South Australian air transport. In: *Proceedings of the 15th Australasian Transport Research Forum.* Vol 15 Part 1, pp.199-208. ATRF, Sydney.

Duldig, P., Findlay, C. and A. Wong (1990) *Regulation, Competition and Congestion: NSW Air Transport in The 1990s.* Government of New South Wales Business Deregulation Unit, Sydney.

Meeke, B. (1980) *A Report to the Premier Concerning Aviation in South Australia.* unpublished.