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Economic Regulation of Air Service to Small Communities: Origins of Airline Deregulation Act of 1978

SAMUEL EWER EASTMAN

In 1947 the Civil Aeronautics Board (CAB) created a new class of certificated air carriers subject to federal regulation of rates and routes and eligible for subsidy—the feeder (later to become local service) air carriers. The purpose was to provide air service to small communities. During the years up to the passage of the Airline Deregulation Act of 1978, the CAB sought to balance pressure for more service and more points served against pressure to hold down rising subsidy costs. They did this by improving or strengthening the local's route structure. In a parallel development to the creation of the local service carriers, in 1952 the CAB formalized the transportation provided by the thousands of fixed-base operators that provide on-demand charter service (and some scheduled service) to small communities by issuing Part 298 of its economic regulations. Part 298 established air taxis as air carriers but exempted them from rate and route regulation subject to a basic limitation that they could not operate aircraft that exceeded 12 500 lb gross weight (about one-half the size of a DC-3). Part 298 was amended in 1965 to relieve earlier restrictions, in 1969 to establish the commuter air carrier class, and in 1972 to increase the allowable aircraft size to 30 passengers and 7500 lb payload. The Airline Deregulation Act of 1978 changed these two regimes of economic regulation that controlled air service to small communities. The act provides that essential air transportation is guaranteed to eligible points and introduced a new subsidy program (Section 219) to underwrite essential air transportation for 10 years if the service could not be provided without compensation. Although the thrust of the deregulation act is to free the airlines, in general, from the regulation of rates and routes, in determinations of essential service to small communities (as of August 1979), the CAB has undertaken to regulate service frequency and aircraft size in greater detail than ever before.

In March 1943 the Civil Aeronautics Board (CAB) had before it applications that covered 16 771 miles of feeder routes and 44 966 miles of airmail pickup routes (1). In response to an "avalanche of pressures generated by chambers of commerce, lower levels of government, prospective local service operators, and other components of the feeder movement", it announced its intention to investigate the feasibility of feeder air service (1). At the time the CAB and the U.S. Postal Service were not enthusiastic about the service due mainly to the prospective costs involved. The examiners in the case confirmed this, but the CAB decided to establish feeder air service on an experimental basis, in part to discharge its statutory responsibility (2, pp. 1-3) "...to encourage the development of an air transportation system properly adapted to the present and future needs of the commerce of the United States, the [U.S.] Postal Service, and the national defense, and to encourage the development of civil aeronautics generally."

ACTIONS TO LIMIT SUBSIDY

Much attention was devoted in the findings of the CAB to ways to limit the subsidy that was to be paid by the government (as it had been for the trunklines) in the form of mail compensation (2, pp. 1-3). A number of safeguards were adopted, including limitation of the certificate of operating authority to three years. To show a justifiable expectation of success, the CAB states as follows (2, pp. 1-3)

> ...It will be incumbent upon each applicant to meet the test of public convenience and necessity by showing a need for the service, the probable use that will be made of it, the effect on existing air services, and a cost to the government in mail compensation bearing a reasonable relationship to these elements and to the character and quality of the service produced.

Later, in the area cases that were concerned with the actual award of feeder routes to particular carriers, the CAB was to limit service eligible for mail pay subsidy to two round trips per day over the route awarded, though the examiners had recommended against such a severe restriction (2, pp. 1-3).

Aircraft Type

The examiners' report showed that the traffic potential of many of the points to be served was small (2, pp. 1-3). Of 88 cities that had populations of less than 50 000 and received air service as of September 1940, 18 cities below 10 000 in population generated 4.05 daily arrivals and departures, 31 cities in the 10 000 to 20 000 bracket generated 5.7 daily arrivals and departures, and 39 cities in the 20 000 to 50 000 bracket generated 13.4 daily arrivals and departures (2). This, along with other considerations, led the examiners to make specific recommendations about the type of aircraft best adapted for local routes. The examiners reported the following consensus among the parties (excluding pickup planes) (2, pp. 1-3):

> (1) Multiple-engined; (2) payload of 2000-3000 pounds; (3) passenger [sic] capacity of 4-12, with appropriate apportionment of the remaining payload for mail and cargo; (4) a copilot who would also act as passenger attendant, ticket seller, cargo handler, and operator of pick-up mechanism where used; (5) cruising speed 150-180 miles per hour; (6) highly maneuverable at low speeds and altitudes; (7) landing speed 50-60 miles per hour; (8) tricycle landing gear, with the design emphasis on crosswind landing conditions; (9) take-off run not more than 1500 feet; (10) folding steps and cabin door which can be opened and closed from the cockpit; (11) space for some amount of luggage in the cabin; (12) bus type interiors without toilet, buffet, hostess facilities, etc.; (13) starter and batteries of sufficient size to dispense with ground batteries; (14) cockpit control of rudder and elevator locking device; (15) cruising range of 300 miles with full load, including fuel load; (16) original cost, including engines, $25 000 to $45 000.

Although the need to achieve economies in operation was recognized in order to keep the cost to the government within reasonable limits, the CAB rejected the examiners opinion with the following language (2, pp. 1-3):

> The examiners, in emphasizing the necessity for such economies, refer to some specific items such as the use of smaller aircraft, operation with a single pilot, the elimination of luxury services, and the reduction of intermediate station personnel. We do not believe it would be appropriate to specify any such items at this time as being prerequisite to the issuance of the certificate. It is obvious that there are many opportunities

for accomplishing a saving in operating costs, but it is equally obvious that all of them could not be adopted in all cases. We believe that more can be accomplished by leaving the details to the ingenuity of the operators and confining our function at present to fostering overall economies.

New Carriers or Feeder Routes for Trunklines

The examiners also noted that, for any appreciable expansion of air service to have a chance of success at a reasonable cost to the government, operators of the new service would have to achieve substantial savings in operating cost over the cost levels of the trunklines at that time. The examiners went on to state (2, pp. 1-3), "Any substantial economy of operation will have to result from departures from the existing type of service. It is reasonable to assume that necessarily different standards of operation can best be developed by new carriers, organized for such a purpose." The CAB agreed. In addition, the trunklines were, by the mid-1940s well on their way to achieving subsidy-free operation. If the local service experiment failed, better to affect a few small carriers that serve minor routes than major carriers that provide the nation's long-haul air transportation. In the CAB's own language (2, pp. 1-3): "Needless to say, we have an obligation to avoid the adoption of any ill-considered policy with respect to a general expansion of air services that would endanger the results thus far achieved under the enlightened national policy established by [the] Act." In the area cases that followed, 19 new local service carriers were established by the CAB. The subsequent history of these airlines, their demises, and their mergers to the present are shown in Table 1 (3, pp. 499-509).

Protect Trunklines and Keep Locals Local

Having created the category of local service carriers, the CAB, in making route awards in the area cases that followed the investigation (2), adopted that policy of requiring the feeder carrier to stop at every intermediate point between terminals on every flight. The purpose was twofold: to make the local service specialist carriers provide feeder service (e.g., serve every point on every flight) and, since the terminal points of many feeder routes were cities that already receive scheduled air service, the trunklines would be protected from the competition of the new carriers. This would be particularly important if there were existing nonstop trunkline service between the two local service terminals.

Eads (1) illustrates the effect on the quality of terminal-to-terminal service by imposing an every-stop-on-every-flight requirement by comparing Southwest's Los Angeles to San Francisco feeder route with a stop in Monterey with the air carriers that operate nonstop. With but a 2-min stop in Monterey, Southwest could fly its 401-mile Los Angeles to San Francisco route in 3 h 45 min (about 87 mph); however, the average nonstop time over the 321-mile straight-line route was about 2 h (between 150 and 170 mph). There is evidence that the restriction on Southwest accomplished its purpose of protecting the nonstop terminal-to-terminal service. In the CAB's March 1949 air traffic survey, only 80 of the 21 164 passengers who traveled by air between Los Angeles and San Francisco used Southwest, and only 68 used Southwest all the way (1).

The CAB protected the trunklines in other ways by the route awards that were made to the locals. For example, United and Western Airlines (both trunklines) objected to a single feeder to serve the entire area between Los Angeles and Seattle because intermediate points would not develop sufficient traffic to support regularly scheduled operations and the local would be compelled to seek nonstop authority. To keep the locals local and protect the trunks, the CAB awarded Southwest feeder routes from Los Angeles to Medford, Oregon, and West Coast Air-

Table 1. Chronology of certification and changes for local service carriers.

Carrier	Date of Certification	Date of Inauguration of Service	Initial Equipment	Change to Large Equipment: Date	Type	No. of Seats	Date DC-3 Phased Out of Service
Air West[a]	April 17, 1968	April 17, 1968	DC-3, F-27, DC-9				
Allegheny[b]	Jan. 1949	March 7, 1949	DC-3	June 1955	M-202	40	Aug. 1962
Bonanza[c]	Nov. 1949	Dec. 19, 1949	DC-3	March 1959	F-27	40	Nov. 1960
Central[d]	Nov. 1946	Sept. 15, 1949	Beechcraft Bonanza A-35—3 passenger				
		Nov. 1950	DC-3	March 1961	CV-240	40	
Frontier[e]	March 1946	Nov. 1946	DC-3	July 1959	CV-340	44	Nov. 1968
Lake Central[f]	Feb. 1948	Nov. 12, 1949	DC-3	March 1961	CV-340	44	
Mohawk[g]	June 1948	Sept. 19, 1948	DC-3	July 1955	CV-240	40	July 1962
North Central[h]	Oct. 1947	Feb. 24, 1948	Lockheed Electra-Lodestar—12 passenger				
		March 1951	DC-3	April 1959	CV-340	44	Nov. 1968
Ozark	Sept. 1950	Sept. 1950	DC-3	Jan. 1960	F-27	40	Nov. 1968
Piedmont	Dec. 1947	Sept. 1948	DC-3	Nov. 1958	F-27	40	Feb. 1963
Pioneer[i]	Nov. 1943	Aug. 1945	Lockheed Electra-Lodestar—12 passenger				
		1946	DC-3	June 1952	M-202	36	[j]
Southern	Feb. 1949	June 1949	DC-3	Oct. 1961	M-404	40	Aug. 1967
Southwest[k]	May 1946	Dec. 1946	DC-3	Nov. 1952	M-202	40	Dec. 1962
Trans Texas[l]	Nov. 1946	Oct. 1947	DC-3	April 1961	CV-240	40	Nov. 1968
West Coast	May 1946	Sept. 1946	DC-3	Sept. 1958	F-27	40	

[a] Formed by Merger of Bonanza, West Coast, and Pacific, April 1968.
[b] Originally certificated under name of All American Airways; renamed Allegheny, February 1953.
[c] Merged with Pacific, April 1968; Pacific changed its name to Air West on that date.
[d] Merged with Frontier, October 1967.
[e] Originally certificated under name of Summit Airways; renamed Challenger Airlines, March 1947; merged with Arizona Airways, June 1950 to form Monarch Airlines; renamed Frontier Airlines, June 1950.
[f] Originally certificated under name of Roscoe Turner Aeronautical Company; renamed Lake Central, November 1950; merged with Allegheny, July 1968.
[g] Originally certificated under name of Robinson Aviation; renamed Mohawk, August 1952.
[h] Originally certificated under name of Wisconsin Central Airlines; renamed North Central, December 1952.
[i] Originally certificated under name of Essair; renamed Pioneer, May 1946; absorbed by Continental, April 1955.
[j] In March 1953 Pioneer was forced to terminate Martin service and reconvert to DC-3s.
[k] Renamed Pacific Airlines, March 1958; merged with Bonanza and West Coast to become Air West, April 1968.
[l] Renamed Texas International, April 1969.

lines was awarded feeder routes from Medford north to Seattle (1).

Subsidy Payment

The examiners recommended the establishment of a maximum mail pay and subsidy rate of 25 cents/plane mile, which would provide substantial scheduled air service coverage of the United States at a cost to the government of $57 million/year (2, pp. 1-3). The recommendation was based on costs of a 10-passenger, twin-engined aircraft, pilot and copilot who doubled as ticket agent and baggage handler, no-frills service, and part-time ground personnel. In its decision the CAB rejected a limit on either total mail pay or on the maximum mail pay per aircraft mile and instead relied on the issuance of a temporary three-year certificate to limit the liability of the government (2, pp. 1-3).

In the first feeder mail rate case, because of the widely varying costs and revenues for a carrier to start-up a new service, the CAB decided to establish a temporary mail rate subject to future readjustment before a permanent future mail rate was established (1). One commentator has suggested that the local service carriers operated essentially on a cost plus subsidy system while on temporary mail pay-subsidy rates, and this was a factor that contributed to the purchase of aircraft larger than needed to provide feeder service (1). As shown in Table 1, the locals had virtually eliminated all but 20-24 passenger DC-3s from their fleets by mid-1953 and, in later years, they bought even larger equipment. DC-3s were initially attractive because they had been operated successfully by the trunklines and would, therefore, make a positive contribution to the image of the new category of carriers created by the CAB to provide feeder service. Moreover, despite their higher operating costs on low-density feeder routes, DC-3s were available at reasonable prices at a time when capital was difficult for the local service carriers to obtain. Congress improved the locals' position in capital markets by making their certificates permanent in 1955 (despite strong opposition from the CAB) and by making government guarantees of equipment loans available in 1957.

LIMITED ROUTE STRENGTHENING, 1958-1965

Mail pay and subsidy payment (later called public service revenues) by the federal government to the local service airlines increased steadily from the mid-1940s to the mid-1950s--from $9 941 000 in 1948 to $32 938 000 in 1958. An exception was a subsidy decrease in 1955 [see Tables 2 (3) and 3 (3)]. In an effort to hold down subsidy costs, the CAB took a number of actions, including progressive lessening of the restrictions imposed on the route awards to the local service carriers.

The CAB's policy of requiring the local service carriers to stop at every intermediate point between terminals on every flight had never been applied absolutely in all cases. As early as 1946, the CAB's route award to Pioneer Airlines allowed it to operate shuttle service between any two points named in its certificate (1). Modification of the requirement to serve all points on every flight in this way was of considerable value because it allowed Pioneer to operate nonstop between Houston and Austin, Texas, in direct competition with the trunklines. The CAB March 1949 air traffic survey showed that, of 1153 passengers who traveled between Houston and Austin, 651 traveled on Pioneer (1).

Further limitations on the restriction were granted to the following airlines (1):

1. To Southwest in 1948 (terminate flight short of terminal point),
2. To All American (later Allegheny) in 1949 (a maximum of three intermediate stops on a six-intermediate-stop route between Pittsburgh and New York but no nonstops between Scranton-Wilkes Barre and either New York-Newark or Pittsburgh, where trunkline service was already operating), and

Table 2. Selected statistics for local service carriers.

	Trunkline					Local Service				
			Avg Passengers per Station					Avg Passengers per Station		
Year	Passengers (000s)	Stations Served	Annual	Daily	Avg Aircraft Capacity	Passengers (000s)	Stations Served	Annual	Daily	Avg Aircraft Capacity
1948[a]	12 324	353	34 912	95	33	426	312	1 365	4	20
1949	14 021	367	38 204	105	36	678	318	2 132	6	20
1950	15 978	385	41 501	114	40	969	370	2 619	7	18
1951	20 622	384	53 703	147	42	1 479	384	3 852	11	20
1952[a]	22 760	385	59 117	162	45	1 735	388	4 472	12	22
1953	26 138	349	74 894	205	49	2 032	356	5 708	16	22
1954	29 347	357	82 204	225	53	2 433	373	6 523	18	22
1955	34 467	357	96 546	265	54	2 940	363	8 099	22	23
1956[a]	37 596	358	105 017	287	56	3 457	367	9 420	26	23
1957	40 273	351	114 738	314	57	3 955	378	10 463	29	24
1958	39 515	348	113 549	311	59	4 265	401	10 636	29	25
1959	44 488	317	140 341	384	63	5 213	439	11 875	33	27
1960[a]	45 184	323	139 889	382	71	5 591	459	12 181	33	29
1961	44 669	304	146 938	403	80	6 470	466	13 884	38	31
1962	46 759	294	159 044	436	88	7 651	477	16 040	44	34
1963	53 380	232	230 086	630	92	8 865	445	19 921	55	35
1964[a]	60 532	234	258 684	707	96	10 481	450	23 291	64	36
1965	69 875	231	302 489	829	98	12 316	468	26 316	72	38
1966	79 382	231	343 645	941	100	15 540	461	33 709	92	42
1967	97 215	232	419 030	1148	102	18 146	459	39 534	108	48
1968[a]	108 986	233	467 751	1278	108	22 177	463	47 898	131	58
1969	129 883	231	562 264	1540	117	24 547	465	52 789	145	65
1970	122 866	218	563 606	1544	117	26 472	433	61 136	167	70
1971	124 351	218	570 417	1563	122	27 432	432	63 500	174	72
1972[a]	136 590	215	635 302	1736	126	30 501	422	72 277	197	72

[a]Leap year (366 days).

Table 3. Ratio of average daily enplanements per station to average aircraft capacity for trunkline and local service carriers.

Year	Local Service Subsidy ($000 000s)	Year	Ratio of Daily Enplanements per Station to Average Aircraft Capacity: Trunks	Locals
1948	10			
1949	14	1948	2.88	0.20
1950	17	1949	2.92	0.30
1951	19	1950	2.85	0.39
1952		1951	3.50	0.55
1953		1952	3.60	0.55
1954	24	1953	4.18	0.73
1955	22	1954	4.25	0.82
1956	25	1955	4.91	0.96
1957	31	1956	5.12	1.13
1958	33	1957	5.51	1.21
1959	43	1958	5.27	1.16
1960	55	1959	6.10	1.22
1961	62	1960	5.38	1.14
1962	67	1961	5.04	1.23
1963	67	1962	4.95	1.29
1964	63	1963	6.85	1.57
1965	63	1964	7.36	1.78
1966	56	1965	8.46	1.89
1967	51	1966	9.41	2.19
1968	41	1967	11.25	2.25
1969	36	1968	11.83	2.26
1970	34	1969	13.16	2.23
1971		1970	13.20	2.39
1972		1971	12.81	2.42
1973		1972	13.78	2.74
1974	67			
1975	57			
1976	70			

3. To Ozark in 1954 (need make only two intermediate stops between terminal points in certificate).

The Seven States Area Investigation, decided in 1958, was a case that was the start of a second round of area cases in which the CAB awarded route authority. In this case, the CAB overruled the examiners' recommendation of the two-stop "Ozark restriction" and stated that it would be general policy to allow the locals to offer nonstop flights between terminals in their certificates where there was no trunkline service. Also, the CAB would require only one intermediate stop where competitive trunkline service existed (1).

This general policy on restrictions to local service routes stood essentially unchanged from 1958 until 1966. The CAB sought to ensure adequate service to intermediate points by the requirement of a minimum of two round-trip services per day. However, the restrictions on awards of local service routes were no longer primarily the financial health of the trunklines (which had all gone off subsidy between 1949 and 1951). Where direct local-trunkline competition resulted, additional restrictions could be imposed on the locals. Rather, the CAB believed that, if the locals were given nonstop authority in noncompetitive markets and one-stop authority in competitive markets, costs would be lower because longer hops and the elimination of unnecessary stops minimize operating costs (1).

Replacement of Trunks by Locals

Another strategy employed by the CAB to strengthen the locals' routes and reduce mail pay subsidy was to suspend trunk service at a point and replace it with a local service carrier. At least 78 stations were involved during the years 1949-1964, and an average of about 9.5 passengers/day were generated. The strategy was probably most successful in strengthening the locals where the trunk suspension took place at a city that formerly received joint service by a trunkline and a local. The 51 cities where this was done averaged 31.2 passengers/day during the last year of joint trunk and local operation, so these were the more important traffic centers to begin with because they had more than three times the average of the 78 cities where trunk service was replaced earlier. For example, Atlantic City, New Jersey, originated 19 511 passengers during 1962 of which 10 620 flew on Allegheny and 8891 flew on Eastern Airlines. Eastern was allowed to suspend service at Atlantic City in 1963; in 1974 there were 20 248 passenger originations from Atlantic City, all Allegheny (1).

Certification of New Points

A third stragegy of the CAB during this time period was to certificate new points for service by the local service carriers. Most of these came from cities that had poorer traffic potential than the cities the CAB had already authorized for local service (1).

> In 1958 the average local station generated 27 passengers a day. The 79 stations added in 1959 (largely as a result of the Seven States Area Investigation) averaged only 4 passengers a day. The 42 stations added in 1960 generated an average of 6 passengers a day, while the 47 stations added during 1961 generated 11 passengers a day on the average. These added stations include trunkline transfers as well as points that had not previously received service, and in general, the former group of stations generated considerably more traffic than did the latter.

Use It or Lose It

In 1958 the CAB formalized a policy that allowed a local service carrier to drop any point that generated less than 5 passengers/day. However, cities resisted (with considerable success) the loss of subsidized air service. In 1966 traffic at 41 of 473 local service points certificated fell below the use-it-or-lose-it standard adopted by the CAB [see Table 4 (1, pp. 119-120)].

Aircraft Type

The theory behind the CAB's route strengthening of the certificates of the local service carriers by (a) modifying the all-points-on-every-flight restriction, (b) replacing trunks with locals, (c) the certification of the locals at new points, and (d) imposing a use-it-or-lose-it requirement at low-density points was to provide for the locals new, larger, and potentially more profitable markets that could offset the losses incurred in the less-dense markets in which they were still required to provide two round-trip services per day. In this way the CAB hoped to reduce the subsidy paid by the federal government.

Route strengthening also encouraged the locals to replace their DC-3s with larger aircraft for operation on their more dense routes. Larger equipment was available in the 1950s and early 1960s from trunkline retirements. At first the CAB resisted replacement of DC-3s. Specifically, when Pioneer replaced all of its DC-3s with 40-seat Martin-202 aircraft in 1952, the CAB disallowed the higher costs associated with the new equipment in computing Pioneer's subsidy payment and paid only the rate

Table 4. Traffic densities by city pair and station for local service carriers.

Avg Daily Passenger Enplanements Generated	Number of City-Pairs 1955	1960	1964	1966
City-pair densities				
Total served	-[a]	5114	6703	-[a]
<10	-[a]	4795[b]	6142[c]	-[a]
>10	-[a]	319	561[d]	-[a]
>50	-[a]	39	93	-[a]
Points served densities				
<5	90	122[e]	-[a]	41
<20	225	-[a]	-[a]	186

[a]Data not reported.
[b]Accounts for 94 percent of the local carrier traffic.
[c]Accounts for 92 percent of the local carrier traffic.
[d]Accounts for 78 percent of the local carrier traffic.
[e]Reflects points added in area cases.

that would have been applicable for DC-3 operations. The larger aircraft lacked adaptability to points served by Pioneer. In the CAB's language (4):

> It is our conclusion that management's forecasts and estimates were unreasonable and that a sound evaluation of the relative profit-and-loss potential to the carrier of the DC-3 and its replacement with the equipment considered and chosen by the carrier should have led to the retention of the DC-3s.

Two other airlines suffered the same fate, one in 1953 and one in 1955.

The 40-seat Fokker F-27 turboprop became available in 1958 and was the first aircraft purchased new in substantial numbers by the local service carriers. At the same time the trunk carriers began to acquire fleets of jet aircraft and large numbers of used M-404s, CV-340s, and CV-440s became available. These and their turboprop conversions, such as the CV-580, were purchased in addition to the F-27 (3). The table below shows the dates of first acquisition of aircraft types by the local service carriers during this period (3, p. 13).

Carrier	Date	Aircraft	Passenger Capacity
West Coast	Sept. 27, 1958	F-27	40-48
North Central	April 26, 1959	CV-340	44-52
Allegheny	July 1, 1959	CV-540	44-52
Mohawk	Aug. 28, 1959	CV-440	44-52
Pacific	Jan. 8, 1960	M-404	40
Frontier	June 1, 1964	CV-580	44-52
Lake Central	Oct. 29, 1965	Nord-262	26-29
Central	Dec. 1, 1965	CV-600	44-52
Mohawk	June 29, 1966	FH-227	40-52

By the late 1950s, the CAB concluded that aircraft larger than the DC-3 were justified on the denser routes, provided some DC-3s were retained for service to smaller communities. In 1959 the CAB approved Mohawk's mixed fleet of DC-3s and CV-240s with the following language (5, pp. 198-202):

> Today, there is abundant evidence that no local service carrier can attain self-sufficiency while flying only DC-3s. The economics of an all DC-3 operation make it clear that a step in the right direction is to reequip with more modern and efficient aircraft when the public will use the added capacity of the larger aircraft. What is more, we believe that the American traveling public is entitled to receive local-service air transportation with faster, more modern, and larger aircraft, providing, of course, that such service can be obtained at a reasonable subsidy cost. It is our expectation that by providing such better service, additional traffic will be stimulated, which, in turn, will ultimately benefit the local carriers by reducing their dependency upon subsidy support.

The equipment-guaranteed loan program enacted by Congress in 1957 materially assisted in reequiping the locals with larger aircraft during this period. As of the end of 1966, the federal government had guaranteed loans for 47 aircraft worth $38 million--all for aircraft of 36 or more seat capacity (1).

Subsidy Payment

One observer has reported that between 1958 and 1960, the local service carriers were on open mail subsidy rates 80 percent of the time, despite the CAB's effort to establish the carriers on final rates. Only at this time, when the CAB and the carrier got around to making the rate final, did the CAB scrutinize the costs incurred during the open-rate period and determine those costs to be excluded from the final rate as not consistent with "honest, economical, and efficient management". Although the CAB could, and did, disallow as excessive costs a portion of executive salaries and mileage flown (which affected the carrier's profits), it was naturally reluctant to disallow a major portion of costs that could bankrupt a carrier, such as the operation of too large an aircraft on light-density routes. In this sense the local service carriers operated on a cost plus basis during periods of open rates (1).

Moreover, under this system of compensation, there was little incentive for a local carrier to invest in higher-cost equipment that had lower operating costs, because the higher operating cost of the older equipment during the open rate period would, in all likelihood, be allowed in determining the final rate. The existence of open rates also made it more difficult for the local service carrier to raise capital because it could not present a firm financial position to a would-be lender. Final rates could be reopened by either the CAB or the carrier based on changes in equipment, route patterns, and economic conditions, so it was difficult for the parties to keep the final rate final. To correct these and other deficiencies, the CAB introduced the class rate in 1961 that established a single subsidy rate for all local carriers. The rate was based on the number of available seat miles flown, adjusted for the individual carrier's density factor (miles flown per station) and experienced rate of return and capital structure (1). In 1963 the class rate was amended to make the subsidy neutral among aircraft, thus a bias was removed that made larger piston-engine aircraft profitable on a larger number of routes (1).

ROUTE STRENGTHENING WITHOUT RESTRICTION, 1966-1969

Subsidy payment by the federal government to the local service carriers increased from $32 938 000 in 1958 to $67 043 000 in 1963 and declined to $56 439 000 in 1966. All of these payment levels were well above that experienced in the 1945-1957 period prior to the introduction of route strengthening by the CAB. The increase in subsidy during the period prompted President Kennedy, in 1962, to instruct the CAB (1)"...to develop ... a step-by-step program, with specific annual targets, to assure sharp reduction of operating subsidies...."

The results of the CAB's route strengthening program in city pairs and points served over the years 1958-1965 are summarized in Table 4. The 1966 route structure of the local service carriers was both strengthened and weakened by CAB policies. It was strengthened by a substantial increase in participation by local service carriers in city pair markets that generate more than 10 passengers/day (from 319 in 1960 to 561 in 1964), which accounted for 78 percent of all local service traffic in 1964; but it was weakened by the increase in participation in city pair markets that generate less than 10 passengers/day (4795 in 1960, 6142 in 1964). The number of low-density points served declined over the period, but in 1966 the locals still provided service at 41 points that generated less than 5 passengers/day--a level of traffic that could not support even DC-3 service and was below the use-it-or-lose-it standard.

The CAB's initial response to the challenge to reduce subsidy was a proposed $43.5 million saving over five years based on (a) reduction in the number of flights per day the government was willing to subsidize, (b) consolidation of airports that were close together, and (c) continued application of the use-it-or-lose-it policy. The program achieved subsidy savings in 1964 and 1965 (1). In 1966 the CAB announced an expansion of the earlier route strengthening policies and applied fewer route restrictions in the certificates of the local service carriers. This provided for the award to the locals of nonstop rights in competition with trunklines in dense short- and medium-haul markets and the award of bypass routes that allowed the locals to overfly traditional traffic hubs into major traffic centers (New York, Washington, Chicago, and Los Angeles). In addition, the CAB allowed three mergers that involved the then 13 local service carriers. To serve these new routes, the locals turned to the purchase of new jet equipment, as shown in Table 5 (1, p. 152).

Table 5. Fleet of the local service carrier industry, by type and model of aircraft.

Aircraft	Number in Service on December 31				
	1966	1967	1968	1969	1970
Piston					
Douglas DC-3	97	58	10		
Convair CV-240	27	8			
Convair CV-340/440	56	27	11	4	
Martin 202/404	77	57	44	38	27
Piper PA-31		4	4	4	0
Beech 99					3
Total	257	154	69	46	30
Turboprop					
Nord N-262	0	12	12	1	0
Fairchild F-27/27J	57	44	41	33	28
Fairchild Hiller FH-227	8	48	48	48	47
Convair CV-600	17	28	35	25	25
Convair CV-580	34	66	96	107	107
Nihon YS-11			8	14	21
Total	116	198	240	228	228
Turbojet					
British Aircraft Corporation BAC-111	9	10	14	20	23
Douglas DC-9-10	9	21	31	30	34
Douglas DC-9-30		7	35	65	73
Boeing B-727	4	8	11	6	5
Boeing B-737			6	17	22
Total	22	46	97	138	157
Total	395	398	406	412	415

During 1969-1972, the CAB reversed its action of previous years and put a moratorium on route awards. In 1972 the CAB's Bureau of Operating Rights completed a detailed study of service to small communities based on the operating data of Air West, Allegheny, Frontier, and Texas International. The study concluded (6) "...in general, operation of the standard 40- to 60-seat aircraft employed by local service carriers is economically justified only at points originating 40 or more passengers a day." And conversely, less than 40 originations means that substantial subsidy is required for the provision of two round-trips a day with standard local service equipment. After 1965 the subsidy paid to the local service carriers had been steadily decreasing, and the carriers had sought to discontinue service on their unprofitable, less-dense routes. The trend toward less certificated service on these routes was hastened by the substantial conversion to jet aircraft that could not operate into many small-city airports (6).

In the early 1970s a movement was articulated, initially by the Council of Economic Advisors in their 1970 annual report (7) to deregulate or at least substantially modify the CAB's authority over rate and route awards of the air carriers. In simplest terms, the council argued that CAB policies encouraged service competition at unnecessarily high rates, and that the carriers should be released from the CAB's heavy hand of economic regulation so that normal competition and market forces could prevail. A major study undertaken by the CAB's Bureau of Operating Rights, published in 1974, confirmed that there was (8)"...an overall volume of service that is excessive in relation to demand in competitive markets." The study manifested a regulatory data-processing breakthrough--It was possible to merge computerized route authority data with traffic, service, and financial data to make a comprehensive assessment of the domestic route system as a system.

These and other events set in motion both Senate and House hearings in the mid-1970s on airline regulatory reform, which ultimately culminated in the Airline Deregulation Act of 1978. But, first the other carriers that provided service to small communities (the Part-298 operators) must be considered to put the legislation in proper perspective. A major argument advanced in the early 1970s by both the trunklines and local service carriers against regulatory reform was that, under deregulation, service to small communities, even as it was known then, would disappear.

AIR TAXIS AND COMMUTER AIRLINES

In 1952 the CAB issued Part 298 of its economic regulations (1), which exempted all air carriers (then known as air taxis) that operated aircraft whose maximum takeoff gross weight was 12 500 lb or less from federal economic regulation and most of the data-reporting requirements the CAB imposed on the other air carriers. As has been outlined above, the local service carriers were subject to minute exercise of the CAB's economic control over routes, rates, and practices, on a case-by-case basis. The air taxis, on the other hand, could initiate and terminate operations as they saw fit at prices of their own choosing with two exceptions: They were not to carry mail nor were they to operate between two certificated points. This limitation was imposed to protect the CAB's route awards to both the trunklines and the locals. The weight limit, based on approximately one-half the takeoff weight of a DC-3 (1), was imposed to protect the locals from air taxi competition. The air taxis were not eligible to receive mail pay subsidy.

During the mid-1950s and early 1960s, thousands of fixed-base operators at large and small airports all over the country provided on-demand air taxi services under the Part 298 exemption. Only a few operators offered scheduled air taxi service. Initially, such service was not viewed favorably either by the CAB or the locals. One operator was TAG airlines, which in mid-1956 operated nine-passenger DeHavilland Doves between Detroit City Airport and Cleveland Lakefront Airport--a popular, frequent, close-in airport service. In the 1960 Great Lakes service investigation, the CAB amended the certificates of both Lake Central and North Central to provide competitive service (1).

The composition of the scheduled air taxi and commuter industry remained fluid (e.g., carriers came and went) which, although hard on the parties affected, is not unusual when a new industry is in the stages of its early growth. Hard facts are difficult to come by since the requirement to report operating data to the CAB was not established until the last half of 1969. In a 1970 study for the Federal Aviation Administration (FAA) (9) it was noted that, as of November 1970, 168 commuter air carriers registered with the CAB, of which 105 were listed as providing scheduled service. Of the 168, 55 (about 1 in 3) were designated by the CAB as new commuter carriers. In the May 1, 1969, Official Airlines Guide (OAG), 98 commuter carriers are listed. In the November 1, 1970, OAG (16 months later) 57 of the earlier 98 were listed together with 39 new carriers not listed earlier. The 1970 study reports that 5 of the carriers listed by the CAB in November 1970 recently declared bankruptcy and that the records of the commuter trade association at the time, the National Air Transportation Conference, show that 17 commuters ceased operations in 1970 (9).

The numbers and kind of commuter aircraft reported to the CAB in 1970 are shown in the table below (9, p. 5). Note that the table excludes aircraft or carriers engaged solely in mail or cargo service.

Number of Seats	Aircraft	Scheduled Commuter Aircraft
≥17	Beech 99	69
	Twin Otter	65
	DH Heron and conversion	19
	DH Dove and conversion	8
	AC-3	5
	Other	10
	Total	176
9-13	Beech 18	62
	Cessna 402	32
	Grumman G-21	19
	Queen Air	18
	Britten Norman Islander	10
	Other	8
	Total	149
≤8	Total	212
Total		537

The Beech 18 aircraft was used largely for mail carriage. The important point to note is that, of the 17 seat and larger aircraft, 69 are Beech 99s and 65 are DHC-6 Twin Otters, together 134 out of 176. The design and construction of these two new turboprop feeder or commuter aircraft resulted, at least in part, from the April 1963 report of the Design Committee of the Association of Local Transport Airlines (ALTA, the subsidized locals' trade association), which called for DC-3 replacement with 18-passenger aircraft that have cruise speed in excess of 300 mph, and pressurization and operating costs of 40 cents/aircraft mile. The 20-passenger Twin Otter was available in 1966 and the 15-passenger B-99 was available in 1967 (3). Thus, although the locals could and did avail themselves of the federal equipment loan guarantee program to purchase large, piston-engined turboprops and the new and even larger jets, the commuter air carriers purchased substantial numbers of two new aircraft types designed to provide service to small communities, and they did it with private funds. Federal equipment loan guarantees were not available to the commuter air carriers until the Airline Deregulation Act of 1978.

In addition to the availability in the late 1960s of new, modern, turboprop aircraft, properly sized for feeder or commuter service, a number of other factors contributed to the stability and growth of commuters. In 1965 the CAB amended Part 298 to allow the carriers that operated under the exemption to carry mail. The restriction that prohibited service between certificated points was also removed.

The latter was important because it paved the way for the commuter replacement agreement wherein a Part 298 exempted-commuter replaced a Section 401 of the Federal Aviation Act of 1958 certificated airline. Responsible commuters that operated the new equipment might be better able to serve small communities (e.g., provide more frequencies in the less-dense markets with smaller equipment) and frequencies that matched local and trunkline connections, that the CAB had awarded the locals, and that could not be operated by them without subsidy. The first such agreement, engineered by Allegheny in 1967, was (and still is) successful. A subsequent attempt, engineered by Frontier, has not been successful.

Commuter Replacement of Certificated Carriers

The first substitute service was at Douglas, Arizona, on July 2, 1967, when Apache, a scheduled air taxi, took over for American Airlines. Allegheny Airlines, in November 1967, proposed to the CAB that its service at Hagerstown, Maryland, be replaced by an air taxi operator who would operate under contract with Allegheny (1). The Beech 99 aircraft to be used in the service was to be equipped to full airline standards, a high level of performance was to be maintained, and reservations would be handled through Allegheny's reservation system. Allegheny agreed to forgo subsidy at Hagerstown and to reestablish service if the experiment was not successful.

The Allegheny commuter (Henson Aviation) was successful. In 1967, 6257 people flew Allegheny's two daily flights. Henson was able to double the traffic in the first year, and in 1976 operated 16 daily flights and carried 42 024 passengers (10). This average annual growth rate of 23.5 percent is far above the traffic growth experienced elsewhere by the trunkline and local service carriers during the same period.

The CAB has since agreed to suspend Allegheny at more than 20 additional points and has allowed other carrier's commuter replacement agreements. As of August 1, 1978, in addition to the 12 commuter airlines that serve points under Allegheny certificates, 4 commuters serve points certificated to Hughes Airwest, 4 serve Ozark points, 4 serve Texas International points, 2 serve points on Delta Airlines, and 1 each serves points on Continental, Frontier, Hawaiian, National, North Central, and Southern.

Flow-Through Subsidy

Although the financial agreements between the certificated carriers and the commuters vary from case to case, all agreements are the same in that no federal government subsidy is paid for providing air service to the certificated point suspended, either to the certificated carrier or to the commuter. Since the commuter uses smaller, less costly to operate aircraft, the argument was made that replacement service could be provided at less subsidy cost to the government if part of the certificated carriers subsidy could be made to flow through to the commuter.

In April 1974 such an experiment was undertaken in which the commuter, Air Midwest, replaced Frontier at Dodge City, Great Bend, and Hutchinson, Kansas. Air Midwest was to receive $131 891 for providing the service, which represented a net reduction in Frontier's subsidy and saved the government $274 109 (11). On July 11, 1975, the U.S. Court of Appeals for the District of Columbia held that, under the law as then written, the CAB could not provide subsidy to an uncertificated air carrier [ALPA v. CAB, 515 Fed. 2nd 1010 (1975)]. Air Midwest and later Air New England were added by the CAB to the list of air carriers eligible for subsidy as a result of this decision. They have been classified as regional air carriers for the purpose of reporting publication only.

Commuter Industry Today

In 1969 the CAB amended Part 298 and recognized the commuter industry, for the first time, by defining a commuter air carrier as an air taxi operator that (a) performs at least five round trips per week between two or more points and publishes flight schedules that specify the times, days of the week, and places between which such flights are to be performed or (b) transports mail by air pursuant to a current contract with the U.S. Postal Service. In 1972 the limits on aircraft size for use by the commuters were raised to minimums of 7500 lb of payload or 30 passengers. Section 38 of the Airline Deregulation Act of 1978 raised the maximum to 56 passengers and 18 000 lb of payload in the case of cargo aircraft.

The commuters, as a category of air carriers, have experienced more rapid growth in the 1970s than have either the domestic trunks or local service carriers. As shown in Tables 6 (12, pp. 12-13) and 7 (12, pp. 12-13), the commuters more than doubled the number of revenue passenger miles flown from 1971 to 1977. Yet, in 1977 they produced less than 10 percent of the revenue passenger miles flown by the locals and less than 1 percent flown by the trunks. The commuter industry is characterized by a large number of small operators--242 reported traffic data to the CAB in 1977, down from 252 in 1976. The top 50 passenger commuter air carriers ranked by passengers are listed in Table 8 (12, p. 14).

Several problems for the commuter air carriers were indentified in 1976 by the CAB Task Force on Service to Small Communities. These included the following (13):

1. The lack of a uniform program of joint fares available to all commuters for commuter or certificated carrier operations,
2. The difficulty commuters have in making arrangements with certificated carriers for interline ticketing and baggage matters,
3. The competitive disadvantage commuters face as a result of OAG policies in refusing to list (a) commuter flights chronologically with certificated carrier flights and (b) commuter connecting flights,
4. The difficulties commuters have in arranging for adequate facilities in the main terminals of major airports, and
5. The high fuel prices commuters are paying because of an inability to arrange wholesale contracts.

Perhaps the most progress has been made for the commuters in the increasing number of interline agreements with the certificated carriers. These are the agreements that cover acceptance of a ticket issued by one carrier by connecting carriers and the handling of baggage and freight from origin to destination over more than one carrier. Table 9 shows that the number of both passenger and freight interline agreements has grown substantially from 1976 through 1978.

Commuter air carriers, from the first days of the scheduled air taxis, have had an image problem because they often operate smaller aircraft from remote terminal locations. Where this has been overcome, the more frequent commuter service has usually attracted additional traffic. [For a discussion on the demand for short-haul air service see Eads (1), p. 11.] A number of problems remain, however. The Airline Pilots Association (the trade association of

Table 6. Selected statistics for commuter airlines.

Item	1977	1976	Change (%)
Carriers reporting	242	252	-4.0
Origin and destination passenger	8 505 453	7 304 996	16.4
Passenger miles	946 179 010	770 783 916	22.8
Cargo (lb)	271 241 568	216 811 423	25.1
Mail (lb)	71 395 261	108 596 524	-34.3
Airports served	764	781	-2.2
Passenger markets	1594	1412	12.9
Total markets	2258	2090	8.0

Table 7. Domestic trunk, local service, and commuter growth rates.

Year Ended June 30	Revenue Passenger Miles (000 000s)			Annual Growth Rate (%)		
	Domestic Trunk	Local Service	Commuter[a]	Domestic Trunk	Local Service	Commuter
1971	95 786.3	7 593.7	442.0			
1972	103 118.0	8 224.6	497.1	7.7	8.3	12.5
1973	112 018.6	9 438.8	549.1	8.6	14.8	10.5
1974	118 186.6	10 573.0	643.5	5.5	12.0	17.2
1975	115 917.4	10 365.2	708.0[b]	-2.2	-2.0	10.0
1976	126 445.3	11 641.4	732.7	9.1	12.3	3.5
1977	134 642.1	12 675.9	834.2	6.5	8.9	13.9
12/31/77[c]	141 276.3	13 541.7	946.2	7.5	11.7	22.8

[a] Includes Caribbean and Alaskan Commuter Carriers.
[b] Air New England, formerly a commuter air carrier, inaugurated service as a certificated carrier in January 1975.
[c] Annual growth rate for calendar year 1977 is based on change from calendar year 1976.

Table 8. Top 50 passenger commuter air carriers.

Carrier Name	No. of Passengers	Carrier Name	No. of Passengers
Puerto Rico International Airlines, Inc.	738 411	Eagle Aviation	114 202
Golden West Airlines	510 449	Bar Harbor Airways	101 556
Ransome Airlines	375 458	Royale Airlines, Inc.	82 677
Air Wisconsin, Inc.	324 581	Command Airways, Inc.	81 314
Metro Airlines—Metroflight	304 413	Air Illinois	78 000
Antilles Air Boats	264 482	Midstate Airlines	75 008
Rio Airways, Inc.	244 823	Commuter Airlines, Binghamton, N.Y.	73 855
Henson Aviation, Inc.	218 837	Southern Jersey Airlines, Inc.	67 701
Pennsylvania Commuter Airlines	205 264	Chautauqua Airlines, Inc.	66 906
Britt Airlines, Inc.—Vercoa Air Service	197 715	Marco Island Airways, Inc.	65 714
Alaska Aeronautical Industries, Inc.	194 204	Scheduled Skyways, Inc., Fayetteville	63 465
Provincetown-Boston Airlines, Inc.	193 603	Mississippi Valley Airlines, Inc.	59 838
Royal Hawaiian Airways, Inc.	184 689	Crown Airways, Inc.	58 100
Swift Aire Lines, Inc.	176 775	Capitol Airlines	54 122
Altair Airlines, Inc.	174 121	Catalina Airlines, Inc.	52 644
Mackey International Airlines	173 930	South Pacific Island Airways	51 227
Rocky Mountain Airways	164 826	Pocono Airlines, Inc.	48 855
Suburban Airlines	157 098	Vieques Air Link	44 443
Cascade Airways, Inc.	152 123	Davis Airlines, Inc.	43 552
Pilgrim Aviation and Airlines, Inc.	139 944	Chalk's International Airline	43 371
Scenic Airlines, Inc., Las Vegas	136 918	Sierra Pacific Airlines	42 027
Aeromech, Inc.	136 367	Florida Airlines	40 814
Air Sunshine—AAT Airlines	134 494	Harbor Airlines—Oak Harbor Airlines	37 640
Air Caribbean	123 227	Columbia Pacific Airlines, Inc.	36 291
Air North, Inc., Burlington, Vt.	115 390	Polar Airways, Inc.	33 308

Table 9. Summary of interline agreements.

	Rank		Number of Agreements with Commuter Airlines		
Certificated Carriers	1978	1977	1976	1977	1978
American Airlines	1	14	34	51	107
United Air Lines	2	1	63	95	105
Eastern Airlines	3	4	50	81	96
Trans World Airlines	4	6	48	76	94
Braniff International	5	5	44	80	91
Continental Air Lines	6	2	58	86	90
Delta Air Lines	7	3	46	82	89
Ozark Air Lines	8	7	48	73	84
Northwest Airlines	9	8	46	71	81
Western Airlines	10	10	31	64	80
Piedmont Airlines	11	9	46	70	78
Allegheny Airlines	12	11	37	58	67
Frontier Airlines	13	13	32	52	63
Hughes Airwest	14	15	36	50	59
National Airlines	15	12	21	56	59
Texas International	16	17	29	47	58
Southern Airways	17	16	33	47	55
North Central Airways	18	19	24	44	47
Alaska Airlines	19	18	29	46	45
Air New England	20	20	17	37	40
Pan American	21	21	1	35	37
Air Midwest	22	22		26	24

pilots of certificated airlines) scope clause restricts the right of certificated carriers from entering into replacement agreements with commuters without the pilots' approval. Since commuter pilots are generally paid less than their certificated counterparts, this affects the competitive cost advantage commuters otherwise enjoy. [See discussion in the CAB report (3), p. 54.] A second problem is the growing congestion at major airports. Since more than 50 percent of commuter traffic is for business and connects with a certificated carrier, the availability of slots or landing positions at connecting airports is an essential element in commuter service and growth.

REGULATORY REFORM AND SERVICE TO SMALL COMMUNITIES

During hearings held in 1974 on the CAB's practices and procedures, the Senate Subcommittee on Administrative Practice and Procedure of the Committee on the Judiciary (Senator Kennedy was subcommittee chairperson) was concerned with the problem of loss of service that might result from regulatory reform. In an effort to obtain empirical information that would tend to show the extent to which increased competition might lead to the abandonment of service to small communities, the subcommittee asked the carriers to submit a list of those routes they believed would likely be abandoned if regulatory control of entry and services were significantly liberalized (without any change in the existing direct subsidy paid to the local service carriers). United Air Lines and the Air Transport Association of America (ATA) responded to the subcommittee request.

United reported that 58 out of the total 327 city pairs (17.7 percent) that it served did not cover incremental costs, were beneficiaries of cross-subsidy, and were therefore candidates for abandonment. After adjustment for routes flown to position aircraft, routes flown for their traffic-generating ability (feeder routes), and routes less than 60 miles in length, 29 route segments remained in the United system (8.9 percent of all route segments) that might lose service if regulatory control of entry and prices were significantly liberalized. The 29 segments averaged 155 miles in length, accounted for 0.5 percent of United's total domestic revenue passenger miles, and United lost $5.5 million in 1974 by serving them.

ATA provided the subcommittee with a study based on the use of a computer model that showed that 372 out of 994 nonstop routes (37.4 percent) flown by the trunk carriers could be candidates for elimination of nonstop trunkline service in the event of liberalized federal regulation. Application of the same adjustments to these data as were applied to the United data leaves 148 nonstop route segments (14.9 percent) that the trunk carriers might cease to serve if federal regulation were changed substantially (14).

The U.S. Department of Transportation (DOT) conducted its own study of air transportation to small communities that challenged the United and ATA studies and went beyond consideration of just nonstop trunkline markets. DOT took the position that the certificated carriers (both trunkline and local service) had for years been abandoning service at low-density points for which they had obtained a certificate of public convenience and necessity. They pointed out that

1. Trunk carriers served 349 points in 1955 but only served 180 in 1975 and
2. Local service carriers served 477 points in 1962 (the peak year) but only served 380 points in 1975.

In addition, DOT showed (April 1976) that both the trunklines and local service carriers serve only a fraction of the markets for which they have authorization and provide service quality equal to the service quality authorized in an equally small percentage of the markets they do serve (15). From this, DOT concluded that the trunklines and local service carriers had already abandoned most of the low-density markets that they did not want to serve.

DOT's analysis concluded that, of 647 points that still received passenger service by certificated or commuter carriers, loss of all air service at 30 points (4.6 percent) would be a high estimate (16) "under complete deregulation and elimination of the present subsidy system." The 30 points that would lose all service were, almost without exception, points that were served by subsidized local service carriers. This DOT result was based on threshold levels of average daily passengers enplaned (ADPE) at these points that, in turn, determine the economic feasibility of commuter passenger service. The points that lose all service are those that have ADPEs too low for commuter replacement service or those at which stable commuter service had not already been established.

Limitations on Commuter Replacement Service

In their testimony on the Aviation Act of 1975 (S. 2551-H.R. 10261), the joint statement of state organizations (17) noted a number of limitations on commuter replacement of service at certificated points. Thus, as of October 1, 1975, the CAB listed 44 points that received service by commuter air carriers as replacement for certificated carriers. This was far fewer than the decrease of 81 points served by the certificated carriers between 1970 and 1975. They reported that this decrease in the amount of air service offered small communities led some states to establish air service both as a replacement for service abandoned by certificated carriers and as new service required in the public interest.

The state interests also recognized that the then regulatory-subsidy local service system had not provided many small communities with the scheduled and coordinated access to the national air transportation system to which they were entitled. Several reasons were reported for this. Of the 44 replacement points noted by the CAB, 27 (61 percent) were replacements by the Allegheny Airlines Commuter System. It would be difficult, if not impossible, reported the states, to establish such a system again due to existing labor agreements. Growth of commuter replacement service offered by the certificated cariers had been hampered by the restictive scope clause in carrier labor contracts and by the refusal of the courts to allow flow-through subsidy in the Frontier-Midwest situation.

The state interests' testimony also noted that, although outstanding examples of commuters operating profitably without subsidy existed, in other situations commuter carriers have had to discontinue service. In Oregon, discontinuance was the result of inadequate financing, faulty community relations, or poor market planning. But the Oregon experience clearly demonstrated to the states the need for commuters that serve small communities to arrange joint fares and schedules with local public or paratransit operators who provided access to the airport from communities within a radius of 15-20 miles.

Failure of the Subsidy System to Provide Service to Small Communities

Whatever the precise loss of service to small communities that might result from major reform of the regime of federal economic regulation of the certificated carriers and the effectiveness of replacing certificated service with commuters, Congress came to the conclusion that the system of subsidy to the local service carriers had failed in its original purpose--to provide feeder service to small communities. The report of the Senate Committee on Commerce, Science, and Transportation on the Air Transportation Regulatory Reform Act of 1978 (S. 2493) addresses this subject by first noting that the Federal Aviation Act contained no statement of congressional policy on service to small communities and that the (10)"...time for creating a system by which the Congress can determine the direction and scope of support for small community service is long overdue." The report reviews the history and earlier studies of the subsidy system and concludes that the CAB, despite its best efforts to reduce total subsidy payments, has not been successful.

The committee was concerned that, although the local service subsidy had increased, the quality and level of service provided small communities had decreased (10). "The primary reason for this trend is the shift of the local service carriers to fleets of large jet equipment which are operationally and economically unsuitable for small community service. Concurrently, the local service carriers have been quietly, but consistently, pulling out of small communities." The committee was convinced that the trend must be stopped.

AIRLINE DEREGULATION ACT OF 1978

After more than three years of congressional hearings and countless studies, charges, and countercharges, Congress passed and the President signed the Airline Deregulation Act of 1978. The act was a compromise of the Kennedy-Cannon-Pearson Air Transportation Reform Act of 1978, passed by the Senate, and the Air Service Improvement Act of 1978, passed by the House.

The act, which is a comprehensive entire overhaul of the Federal Aviation Act of 1958, reduces the CAB's economic regulatory power over the routes and rates of the certificated carriers, provides for the CAB to transfer such remaining authority as it has to other federal agencies by January 1, 1985, and cease operations (sunset provision). It phases out the present subsidy (with some changes) to the local service carriers in seven years, extends the equipment loan guarantee program for five years, and makes commuter air carriers eligible for participation. Moreover, a new statement of policy regarding service to small communities is added. The act declares the public interest to be "the maintenance of a comprehensive and convenient system of continuous scheduled airline service for small communities and for isolated areas, with direct federal assistance where appropriate."

New Subsidy Program

To provide for direct federal assistance where appropriate, the act adds Section 419 to Title 4 of the Federal Aviation Act of 1958. The new section charges the CAB with the responsibility of providing "essential air transportation" to "eligible points" and, if the CAB finds that essential air transportation will not be provided to any eligible point without compensation, the CAB is to establish a rate of compensation to be paid for providing essential air transportation. This new subsidy program is to last for 10 years from enactment of the legislation, and the authority to provide compensation for air transportation is to be transferred from the CAB to DOT on January 1, 1985.

Eligible points are defined as all cities listed on air carrier certificates on the date of enactment, including cities at which a certificated carrier has suspended service. Essential air transportation is to be not less than two daily round trips, five days a week, or the level of service actually provided during calendar year 1977. The legislation also provides for the addition of a limited number of new communities to be added to the new community-based subsidy program.

The act also includes specific provisions for the replacement of a subsidized carrier. After January 1, 1983, any carrier may file an application to replace a local service carrier that received subsidy under the old program (18): "The board is directed to grant the application if the applicant shows that it can provide a substantial improvement in the air service being provided and a decrease in the amount of compensation which is required. Any replacement service would be compensated under the new subsidy program." Under similar provisions, applications can be made to replace carriers that operated at a point for two years under the new subsidy program.

Aircraft Type

Guidelines for compensation are provided in Section 419(d) of the legislation. They are to "...include expense elements based upon representative costs of air carriers providing scheduled air transportation of persons, property, and mail, using aircraft of the type determined by the board to be appropriate for providing essential air transportation to the eligible point." The conference report states that the compensation is to be based on the needs of the community and the use of appropriate aircraft (18).

Implementation

The Airline Deregulation Act of 1978 addresses the major problems that have impeded service to small communities, as those problems were identified in the legislative history. Thus the act

1. Makes a deliberate switch in policy in that the communities are to be subsidized, not the carriers;
2. Guarantees service to a selected group of communities;
3. Makes subsidy available to the commuters that operate smaller aircraft; and
4. Requires the CAB to determine the appropriateness of the aircraft type in determining the compensation to be paid.

Although any conclusion as to the success of the act in addressing these matters would be woefully premature, a few comments about how the CAB and its staff have handled implementation of their new legislative responsibilities is appropriate.

Air Service at Carlsbad, Clovis, and Hobbs, New Mexico

In 1978 Texas International Airlines, a subsidized local service carrier, provided the only certificated scheduled air service between three small communities in New Mexico (Carlsbad, Clovis, and Hobbs) and Albuquerque, New Mexico. Two round trips were made daily by using 40-seat Convair 600 aircraft on a routing from Albuquerque to each of the three cities and back again five days a week, and a single round trip was scheduled on Saturday and Sunday. Average daily enplanements (excluding those of noncertificated carriers) at Carlsbad, Clovis, and Hobbs during the 12 months ended June 30, 1978, were 20.7 22.1, and 19.4 passengers, respectively.

Texas International Airlines alleged to the CAB that it suffered substantial losses by serving this level of traffic with the 40-seat Convair 600, and on June 23, 1978, they petitioned for authority to suspend service at the three points. On July 21, 1978, Air Midwest, also a certificated carrier, applied to the CAB for a subsidy-eligible route segment that included service between the three small communities and Albuquerque. These filings generated a number of responsive pleadings and, after enactment of the Airline Deregulation Act on October 24, 1978, additional filings and petitions were made by, among others, the three communities, which asked the CAB to determine the level of essential air transportation service at each point, and by two commuter carriers, Crown Aviation and ZIA Airlines, which offered to provide substitute service for Texas International.

In its order (CAB Order 78-12-151, Dec. 21, 1978), the CAB determined, among other matters, that before Section 419 subsidy can be provided for essential air service at small communities, it must first be shown that essential service cannot be provided without federal compensation. The CAB went on to make an interim determination of essential air service for each of the three communities; to determine Crown, ZIA, and Air Midwest fit, willing, and able to perform that service without subsidy; and to grant Texas International an experimental 90-day suspension of service conditioned on the replacement carriers that meet the required level of essential service.

Two-Tiered Equipment and Frequency

In making an interim determination of essential air service, the CAB specified one of two levels of aircraft size and frequency (or presumably some combination of the two) in the following language, taken from the order of December 21, 1978:

> For each point 12 nonstop round trips per week (or 24 one-stop round trips per week) between each community and Albuquerque with aircraft having 15 seats or more, to include no less than two round trips daily, Monday through Friday, and one daily round trip each weekend day.
>
> If smaller equipment is used, at each point 24 nonstop round trips per week or 48 one-stop round trips per week, with no less than four round trips daily, Monday through Friday, and two daily round trips each weekend day.
>
> The equipment must be at least twin-engined aircraft meeting all FAA requirements.

Thus, the Airline Deregulation Act of 1978 has swung the CAB full circle from its refusal in the late 1940s to influence the carriers in their selection of equipment. In this case there is a choice, essential air service can be met one of two ways. It is two-tiered: two sets of aircraft size and flight frequency. Either or a combination of both will meet the requirement.

Proposed Guidelines: Essential Air Transportation

The act requires the CAB to set the essential service level for the initial 555 eligible points by October 24, 1979. On May 3, 1979, the CAB issued two notices of proposed rulemaking to implement Section 419. Both were directed toward the determination of essential air service to each eligible point: One was devoted to proposing the procedures to be used (collective or individual point determination) (20), and the other proposed guidelines for use in essential air service determinations (21). Putting procedure to one side, the proposed guidelines identify four service factors to be considered in determining essential air transportation service (for points other than in Alaska)--hubs, equipment, frequencies including scheduling, and stops. The proposed guideline for the first and last of these factors is, in simplest terms, that essential service should consist in the usual case (and many exceptions are noted) of not more than two-stop service to the nearest hub (a point enplaning 0.05 percent or more of all passengers enplaned by certificated carriers in the United States).

Equipment and Frequencies

For equipment--the size and type of aircraft to be used in providing essential air transportation--the CAB's guidelines do not specify that a particular aircraft size be identified. Rather, they propose that FAA's safety standards be relied on. Aware of some public reluctance to accept small aircraft along with the experience on the other side that more frequent service with smaller aircraft has proven successful in developing traffic, the CAB was unwilling to set a minimum size in the proposed guidelines. For example, a lower limit of 10 seats would effectively ground a large portion of the commuter fleet and thus delay establishment of essential service to eligible points. Similarly, pressurized equipment was tentatively not required in the usual case.

Prohibition of service by FAA-certificated single-engined or single-pilot aircraft would have the same effect. The guidelines, however, define essential air service in the usual case, as service by at least twin-engined aircraft with a pilot and copilot. The grounds stated are that service quality, in addition to safety, is the standard to be maintained in this instance.

The guidelines-proposed service frequency is a minimum of two daily round trips, Sunday through Friday, to each designated hub point, and a lower level of service on Saturday, depending on traffic at the point on that day. Flights are to be operated at reasonable times (21) "geared to the nature of the traffic"--morning and late afternoon for one-day round trip business travel, and to match connecting arrivals and departures at the hub. Aircraft size and frequency of service, taken together, are to achieve approximately a 65 percent load factor.

Congress established a minimum guaranteed level of service to small communities, but no maximum. The guidelines adopt the philosophy of the act--minimum government interference--and propose that a self-sufficient service is provided when more than 40 passengers/day are enplaned at a point. At approximately 65 percent load factor, this would be 60 available seats each day in each direction (120 seats each day altogether). This is a level of service beyond which the CAB would not ordinarily guarantee service, a level of service that should be economically self-sufficient and not require federal subsidy. This service requirement could be met with two round trips with 30-seat aircraft or four round trips with 15-seat aircraft or some other combination of frequencies and equipment. If intermediate points (between the eligible point and the hub) or beyond points are served, so that the available aircraft capacity is shared with other markets, an increased number of flights or turnaround operations would be required to meet the proposed guideline of 60 seats in each direction.

This language in the guidelines is consistent with the language in the CAB's order on air service at Carlsbad, Clovis, and Hobbs, New Mexico. A particular aircraft size is not specified to meet the essential air service requirement. Rather, based on ADPEs at the point and a 65 percent load factor standard, two alternatives of equipment size and frequency are determined. One may speculate that the CAB has adopted, or is in the process of adopting, a two-tiered standard of aircraft size and service frequency in determining essential service at eligible points as directed by the Airline Deregulation Act of 1978.

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Response to Terminal Access Problems at American and United Airlines—John F. Kennedy International Airport

FRANK LaMAGNA AND EDWARD M. WHITLOCK

Air travel at Kennedy International Airport has increased so much that ground transportation systems have become taxed beyond practical capacities. American and United Airlines, in conjunction with the Port Authority of New York and New Jersey, decided to act expeditiously to reconcile bottlenecks in front of the two respective terminals. Surveys were conducted of all traffic on the ground, including pedestrians and vehicles. Findings concluded that (a) curb frontage was insufficient; (b) much of the congestion resulted from the close proximity of the American Airlines exit roadways and United Airlines entrance roadways; (c) substantial through traffic on the same roadways was interacting negatively with the traffic destined for the American and United Airlines terminals; and (d) parking regulations were not being enforced sufficiently. Major change was suggested on the road system and new roads were constructed, which required taking a portion of the parking lot in the central terminal area. Further, through traffic was assigned to a new road system and diverted to a new road on the back side of the parking lot. Crossover areas were eliminated between the two terminals and new, independent hold areas for taxis were developed. Finally, commercial vehicles were separated from private vehicles and new regulatory measures were inaugurated to achieve necessary order and dignity, and thereby eliminate chaos. Construction commenced immediately, and all aspects of the recommended plan were completed within nine months. At a cost of some 100 parking spaces, a new road system produced substantial amenity for all ground travelers. The owners are of the opinion that the benefits far outweigh the costs. This project is a successful example of how carefully designed surveys and total cooperation between owners and operators can result in a properly engineered and constructed project to provide necessary amenity and utility to major ground vehicle-pedestrian congestion.

Continued escalation of air passenger volumes has created burdens on the existing roadway and curb frontage facilities at many air terminals throughout the world. This was the case at the American and United Airlines terminals at John F. Kennedy International Airport.

The airport was designed and opened in the 1950s to accommodate approximately 16 million passengers annually. Since then, the basic roadway system was modified to accommodate 21 million passengers in 1976 and 27 million passengers in 1980.

As passenger traffic continued to escalate, airport authorities undertook studies to revise the present road concept and devise a master plan that would eliminate much of the congestion and provide adequate capacity to handle future air passengers. Because these plans were long term, American and United Airlines, with the cooperation of the Port Authority of New York and New Jersey, indicated their desire to develop plans that could alleviate some of their immediate problems, in view of the expected growth patterns.

PLANNING PHASE

To obtain a thorough knowledge of traffic activities, an extensive field study of all travelers was conducted at the American and United Airlines terminals. The date and time of survey were chosen by the carriers and consultant, Wilbur Smith and Associates, as representative of typical peak-period activity.

Figure 1 identifies the traffic survey stations and roadway configuration in existence at the time of the study. The existing roadway system was a one-way configuration that had free turns, merging lanes, and required minimum stops except at grade-level pedestrian crossings.

Special in-depth roadway surveys and passenger interviews were conducted to trace the vehicle paths in the vicinity of the two terminals. The studies provided passenger characteristics that were useful in developing future plans, including the following:

1. Mode of arrival and departure;
2. Arrival distribution patterns of passengers;
3. Number of visitors versus passengers;
4. Parking duration patterns at long-term and short-term parking lots; and
5. Vehicle dwell and loading-unloading times at curb.

Some of the key survey results are shown below and were the basis for the development of future plans.

Item	Number
Peak-hour passengers, American and United Airlines terminals	
Enplanements	990
Deplanements	1020
Total	2010
Transfer passengers, enplanements (%)	18
Vehicles entering terminal area during peak hours	2085
Vehicles using curb frontage roadways and exiting (%)	46
Vehicles using curb frontage roadways and parking (%)	7
Vehicles parking directly (%)	12
Vehicles exiting area directly, through traffic (%)	35
Visitors per passenger	
American Airlines terminal	0.9
United Airlines terminal	0.6
Pedestrians crossing airport roadway during peak hours, both directions	
American Airlines terminal	500
United Airlines terminal	435

During the peak hour, a total of 2085 vehicles entered the American and United Airlines terminal areas. Of these, 730 vehicles were oriented to other terminals at the airport. The arrival patterns of passengers prior to scheduled departure are shown in the table below.

Minutes Prior to Scheduled Departure	Percentage of Persons Arriving	
	American	United
0-15	6	9
15-30	18	14
30-45	20	16
45-60	16	23
60-90	14	26
90-120	12	9
>120	14	3

Vehicle dwell times are given in Table 1.

The study resulted in two types of improvements:

1. An immediate action plan to be implemented within three months and
2. A short-term improvement plan to be implemented within one year.

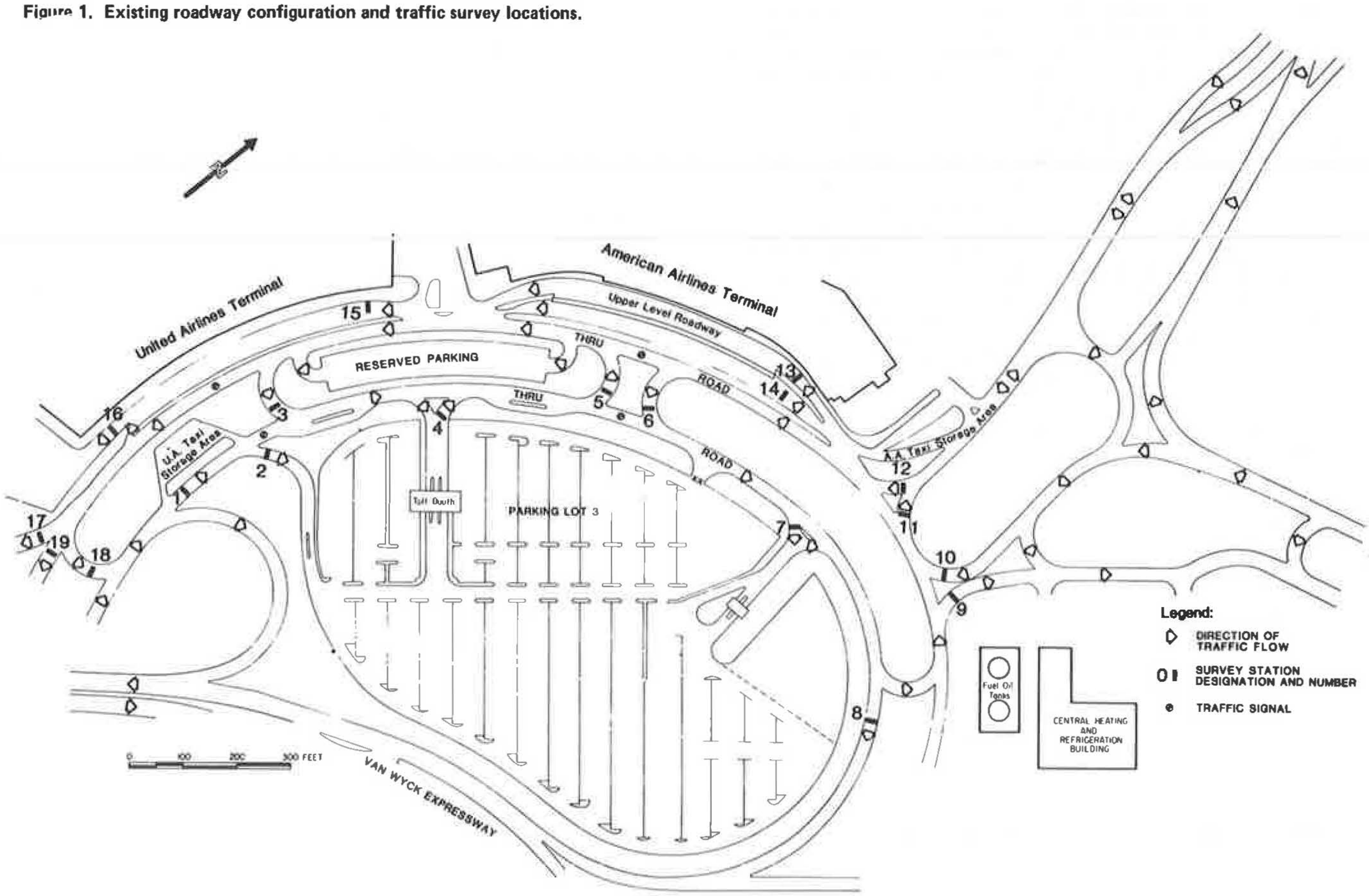
Immediate Action Plan

Because many of the passengers on the airport roadway are infrequent travelers, some confusion on the roads and a misorientation of vehicles add to the congestion problems. Figure 2 presents the immediate action plan for the two terminals. The plan was developed to provide low-cost traffic engineering improvements that would ease congestion and improve traffic flow.

The immediate action plan to be implemented within three months recommended the following improvements:

1. Provide a more informative and easily understood signing program to reduce the amount of through traffic,
2. Increase roadway lighting intensity on various roadway segments (the low intensity in lighting

Figure 1. Existing roadway configuration and traffic survey locations.



limited visibility and caused drivers to reduce speed),

3. Close certain turn-around roadway portions opposite American Airlines and United Airlines terminals (during peak hours, congestion resulted from vehicles that crossed the outer through roadway and backed up onto the inner-loop roadway),

4. Monitor and enforce vehicle activities at the curb,

5. Modify taxi queue lines and operations, and

6. Use baggage carousel locations and curbside check-in areas to provide a more even distribution of curb use.

The studies and analyses identified and quantified three basic problem areas:

1. Considerable congestion results from the close proximity of the American exit roadway and the United entrance roadway, which compounded the backups and delays;

2. Significant amounts of through traffic oriented to other terminal buildings at the airport use roadways that serve American and United Airlines; and

3. Insufficient curb frontage area exists to accommodate increases in vehicle activitiy.

The photographs in Figure 3 identify these areas.

The most predominant congestion occurred at the crossover point between the exit of American Airlines enplaning (departures) and deplaning (arrivals) roadways and the entrance to the United Airlines terminal curb frontage. The design capacity for this roadway crossover section at level of service C is estimated at 800 vehicles/h. During the peak hour of survey, more than 1200 vehicles used this roadway section.

Field surveys also indicated that many of the private automobile drivers on the airport roadways were using the roadway system for the first time. As a result, some vehicles seemed to wander through the road system in an effort to reach their destination or to exit the airport. Studies indicated that about 35 percent of the total vehicles were through vehicles that did not stop at either terminal or use parking lot 3.

Other areas of congestion were noted along the curb frontage areas of the two terminals. Many vehicles parked for extensive time periods, which limited the availability of curb frontage, in addition to a general lack of curb frontage capacity to accommodate the traffic flow. Future projections of air passengers provided by the carriers were used to

Table 1. Curb frontage vehicle dwell times.

	American Terminal (min)		United Terminal (min)	
Vehicle	Enplaning	Deplaning	Enplaning	Deplaning
Automobile	2.4	2.6	2.2	2.9
Taxi[a]	1.4	1.3	1.3	1.4
Bus	1.9	1.0	1.5	1.5
Limousine	2.3	2.6	3.0	4.0
Courtesy van	1.5	1.3	1.5	1.5

[a] During a six-hour period, 620 taxis were required at the American Airlines terminal and 800 taxis were required at the United Airlines terminal.

Figure 2. Immediate action plan—1977.

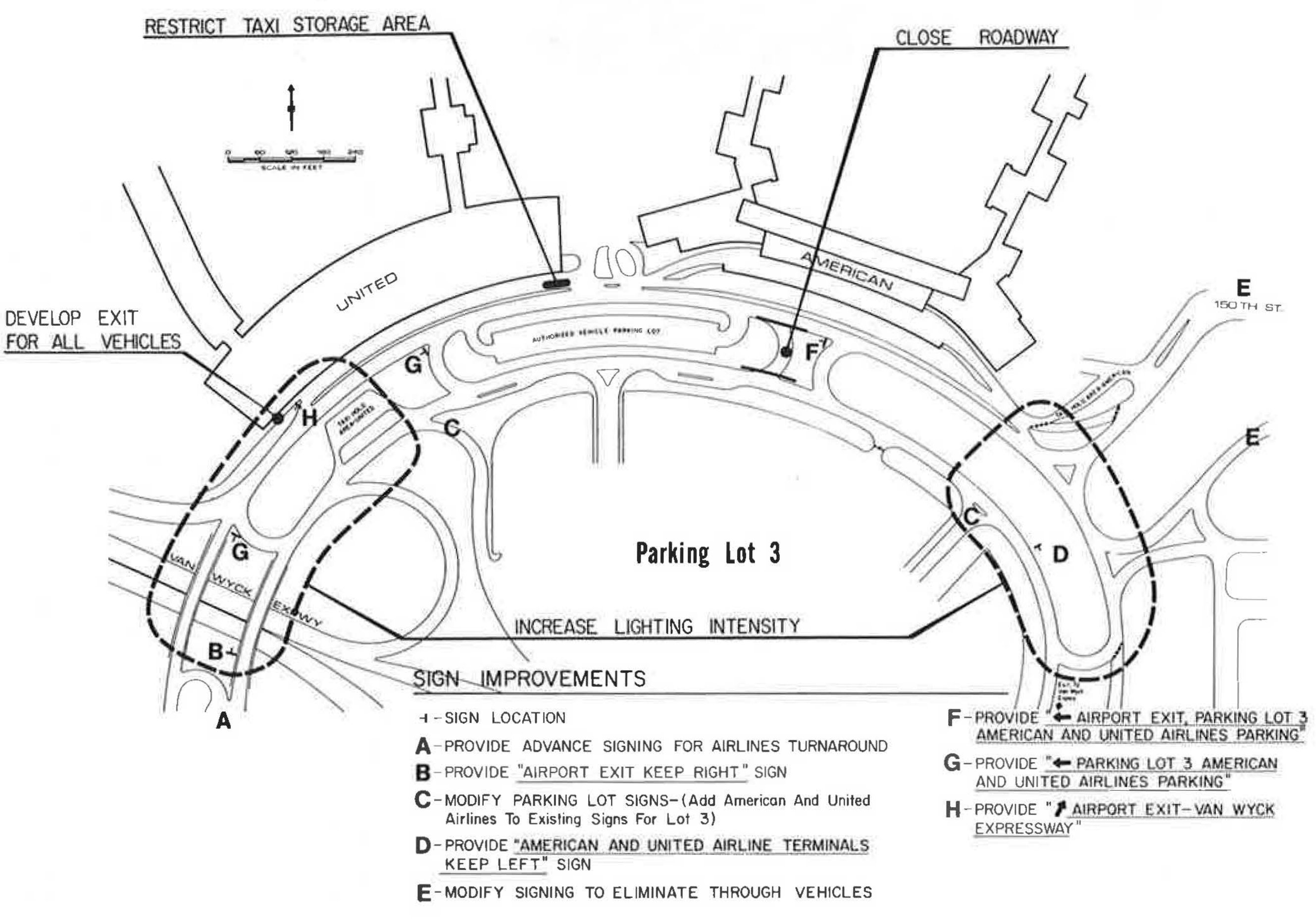


Figure 3. Existing areas of congestion.

Table 2. Summary of future American and United Airlines terminals peak-hour vehicle trips for an average day during a peak month.

	American Airlines Terminal		United Airlines Terminal		Combined Terminals	
Mode	Enplaning	Deplaning	Enplaning	Deplaning	Enplaning	Deplaning
Automobile, park directly	75	50	80	25	155	75
Automobile use of curb frontage	210	195	240	75	450	270
Taxi	240	200	280	75	520	275
Limousine	25	25	15	10	40	35
Public bus[a]	20	20	20	20	20	20
Car rental bus[a]	15	10	15	10	15	10
Total	585	500	650	215	1200	685
Visitor automobiles, park directly	30	30	25	10	55	40
Total	615	530	675	225	1255	725

[a]Assumes dual use of vehicle at terminals.

determine long-range needs at the terminals. Estimated air passenger forecasts predicted a 70 percent increase in peak-period (5:00-7:00 p.m.) activity.

Table 2 presents the results of the analysis of future peak-hour traffic activity for the two terminals. As noted, about 2000 vehicles are expected to be in the areas during the peak hour of an average day in a peak month. More than 80 percent of these vehicles are expected to use the curb frontage, resulting in a total need for about 1900 linear ft of curb at the American Airlines terminal and 1400 ft at the United Airlines terminal, as shown in the table below.

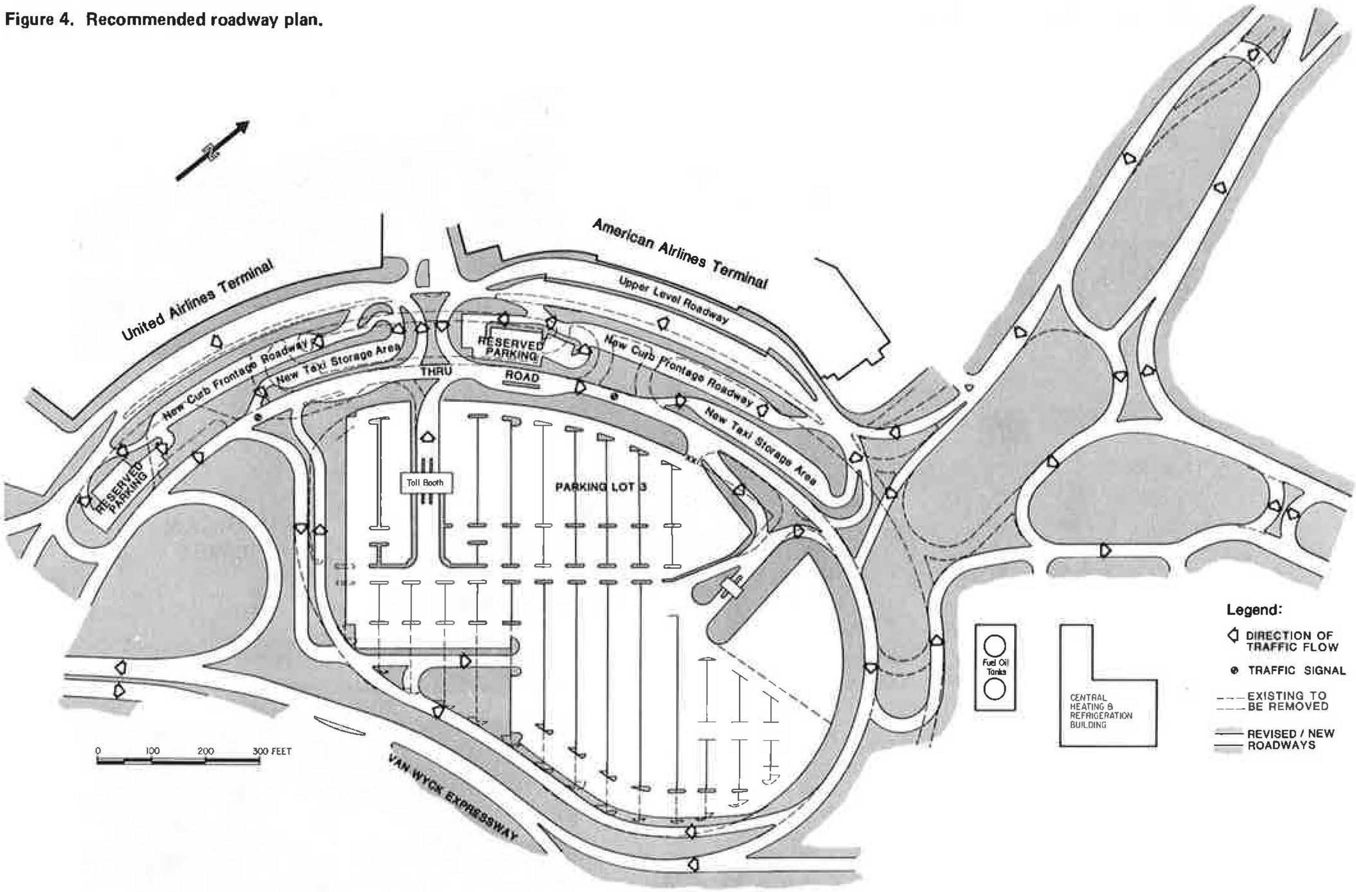
	Curb Frontage Requirement (ft)	
Terminal	Enplaning	Deplaning
American Airlines	675	1250
United Airlines	650	700
Combined	1325	1950

The analysis made evident that roadway revisions must be made in order to accommodate future traffic.

Short-Term Improvement Plan

At this point in time, the airlines were experiencing an overwhelming increase in passenger traffic.

Figure 4. Recommended roadway plan.



As a result, short-term roadway improvement plans that could be implemented readily were developed in conjunction with the air carriers and the Port Authority. These included the addition of approximately 450 ft of additional curb frontage to each of the terminals, elimination of the conflicts of the entrance-exit weave at the terminal buildings, and authorization to design and supervise construction of the project.

Along with developing a plan to facilitate the immediate needs of the two carriers, the plan had to be responsive to long-range needs to further expand the existing roadway system at Kennedy International Airport in response to the increased traffic demand throughout the entire airport complex. The airlines and Port Authority helped in formulating a plan, shown in Figure 4, that includes the following features:

1. Widening of existing lower level curb frontage roadways to 44 ft,
2. Provision of a second lower level curb frontage roadway that has a 44-ft width at the United Airlines terminal and 55-ft roadway width at the American Airlines terminal,
3. Possible segregation of traffic on the curb frontage roadways,
4. Reduction of through vehicles from the roadway system,
5. Elimination of the existing traffic congestion-crossover area between the two terminals,
6. Provision of adequate independent taxi storage areas,
7. Maintenance of the existing pedestrian walking distance to and from the parking lots and provision for safe crossings,
8. Provision of a reserved parking lot at each terminal building, and
9. Provision of a pedestrian canopy and lighting over the new curb frontage island.

CONSTRUCTION PHASE

The project included the relocation of a bus maintenance yard; new roadway signing, lighting, and drainage; and a pedestrian canopy.

Key to the design was the construction staging necessary to complete the project with minimum disruption to the daily operations of both terminals. A complex construction staging plan was developed to facilitate most of the pedestrian-vehicular access throughout the area. Construction on the roadway portion of the project began in June 1978 in an effort to complete the roadway portion of the project within the 1978 construction season. The initial stage of construction required completion of all new entrance and exit roadways from the respective terminals, as well as all the external roadway segments.

Two months later, all necessary elements were in place in order to discontinue the through roadway, most closely adjacent to the terminals, from the airport roadway system in the vicinity of the American and United Airlines terminals. Barricades were strategically placed in a previously planned sequence of events to ensure the safe operation and ability of vehicles to continue to their destination without undue delays.

As parts of the elimination of the outer through roadway, close coordination was necessary with the Port Authority of New York and New Jersey and the roadway contractor. Newly installed signs had to be in place and uncovered and old signs bagged so that

Figure 5. New roadways and canopy at American and United Airlines terminals.

motorists would be properly directed to their destinations during this sequencing of construction.

The entire conversion of the roadway system took approximately 6 h and used extensive manpower and more than 2500 linear ft of vehicle barricades. The only problem that arose during the rerouting of traffic was in communicating effectively with the vehicle drivers most familiar with the old airport road network (taxis and buses)--they neglected to observe and follow instructions of the new signs.

Construction continued and focused on the exclusive areas of the terminals; that is, the new curb frontage roadways, pedestrian islands, and very important persons (VIP) parking lots. Because of the significant amount of traffic oriented to the terminals, extensive maintenance and protection of traffic practices were employed to permit the terminals to continue their operations. The major underlying factor within this construction project was not to restrict or shut down terminal or roadway operations. The project continued for approximately two more months, at which time the project was essentially complete, except for minor items.

The most important features of the revised roadway plan enabled American Airlines to segregate private and public vehicles on the deplaning roadway and, at the United Airlines terminal, enplaning and deplaning traffic could be segregated. Only one curb frontage area previously served the United Airlines terminal. In addition, the plan also provided a VIP parking lot that has a capacity of about 35 spaces at each terminal. Access to these lots is controlled by card actuations and radio control.

The second phase of the project involved the design and construction of pedestrian canopies on the newly installed canopy islands. As the plan always contained this aspect of the design, all necessary footings, anchor bolts, conduit, and drainage for the canopy were contained in the canopy islands under removable sidewalk panels as part of the roadway project. Thus, the installation of the canopy could also be undertaken with minimum interruption to the newly installed roadway operations. The canopy project was awarded in November 1978 and was essentially complete by Easter 1979. Figure 5 shows the newly completed roadways and canopy.

The total construction period took about one year because construction was done on weekends and after normal working hours.

PLAN BENEFITS

Completion of the roadway modifications offered many benefits to both the airlines and air passengers. Although the actual benefits of the project are difficult to measure, a comparison of activity level

Table 3. Comparison of activity at American and United Airlines Terminals.

Item	November 19, 1976		November 21, 1980		Change (%)	
	American	United	American	United	American	United
Traffic volumes, 4:00-5:00 p.m. (vehicles)						
Frontage roads	705	480	875	575	+24	+20
D-road opposite terminal	790	840	1250	950	+58	+13
Traffic volumes, 4:00-7:00 p.m. (vehicles)						
Frontage roads	1620	1185	1850	1525	+14	+29
Inner through road opposite terminal	2300	2075	3100	2300	+35	+11
Passenger volumes—departures, 4:00-7:00 p.m.	1280	1265	1350[a]	1410[a]	+6	+12
Vehicle dwell times, private automobile (min)						
Arrival	2.4	2.2	2.3	2.0		
Departure	2.6	3.1	2.6	2.5		

[a]Estimated number of passenger departures includes transfer passengers and an estimate of all other passengers served at the terminal.

was undertaken on Friday, November 21, 1980, four years after the original survey. Table 3 presents a summary of comparative activity at the American and United Airlines terminals at Kennedy International Airport. In summary, the table indicates that a greater amount of vehicular and air passenger traffic is accommodated at the two respective terminals. During the peak hour, a 20 percent increase in vehicles that use the curb frontage roadways was observed as compared with 1976 conditions. Of importance, however, is that the roadways that serve the two terminals operated in the absence of delays and provided improved levels of service to the airline passengers. The increased capacity has also enabled the airlines to manage their respective curb frontage roadways better, as indicated in the reduced vehicle dwell times observed. Overall, the plan has been well received by both air carriers, airport officials, and air passengers. Like many planned improvements, however, there are both disadvantages as well as benefits when the planned improvements to the overall airport are weighed. Implementation of this plan has had the following adverse effects at Kennedy International Airport:

1. Travel times between some terminals have increased due to the discontinuation of the through roads;
2. As a result of increased traffic on the inner through road the Port Authority has widened the inner through road in front of the American Airlines terminal, modified the parking lot access-egress operations, and made other minor roadway improvements at other terminals and revised signing; and
3. A slight reduction in short-term parking use in the central terminal area (parking lot 3) has been noted.

Some of the more noticeable benefits at the terminal roadways that serve the American and United Airlines terminals include the following:

1. Improved vehicle ingress and egress,
2. Substantial increase of curb frontage area,
3. Elimination of the majority of non-American or United Airlines terminal traffic,
4. Better traffic management capabilities,
5. Segregation of private and commercial vehicles at the American Airlines terminal,
6. Separation of arrivals and departures at the United Airlines terminal,
7. Individual taxi queue areas that have direct terminal access to reduce the problem of illegal taxis,
8. Reduced passenger complaints about terminal traffic,
9. Increased area lighting for driver comfort, and
10. Individual terminal VIP parking areas.

Prior to construction of the new roadways and curb frontage areas, during peak periods of activity, terminal traffic congestion caused significant delays. The completion of the project reduced this problem substantially and provided order in traffic operations at the two terminals.

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Automating the Delivery of Ground Transportation Information

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This paper introduces the concept of an automated ground transportation information system (AGTIS) for use at major intermodal transportation terminals. The AGTIS uses a touch-sensitive cathode-ray-tube terminal to facilitate input to a computer-based information-retrieval system. The patron uses the touch-screen terminal to indicate an ultimate destination and then receives visual information on the travel time, cost, and availability of transportation services to that destination. After selecting the most appropriate service, the patron then receives detailed printed instructions for its use. A prototype system has been set up at the Transportation Systems Center. Full working demonstration projects are expected to be installed at Boston's Logan Airport and Washington D.C.'s National and Dulles Airports. These systems will be closely monitored to assess their efficiency in delivering transportation information and to evaluate their impact on the mode choice of air passengers.

The traveler who arrives by plane, train, or bus at a major transportation terminal is often faced with an immediate problem, how to get to his or her final destination. This problem becomes particularly complex at a large hub airport where a wide variety of taxicab, bus, limousine, and sometimes rail services are provided. Because air travelers are usually in a hurry, information they receive on the availability and current status of such services must be delivered quickly. Otherwise, most will be inclined to use low-occupancy vehicles, such as taxis, rental cars, or private automobiles, and thereby increase traffic congestion and energy consumption.

A similar problem is presented to the airport operator. The operator wants to dispense ground transportation information efficiently and accurately to the airport user. However, the increasing number of air passengers combined with rapidly escalating personnel costs make it more and more difficult to provide the level of information that passengers need to select the ground transportation service best suited to their time schedule and budget.

Traditionally, airports have used three basic methods for delivering ground transportation information: (a) brochures, (b) personnel (at booths or via phone), and (c) signs. A brief survey of 12 large hub U.S. airports evaluated the effectiveness of these methods against the criteria listed below:

1. Is the information comprehensive?
2. Is it easy to understand?
3. Can it be easily updated?
4. Does it provide quick access to the air traveler?
5. Is it location specific (i.e., can information for a particular destination be isolated)?
6. Does it permit intelligent decision making? and
7. Can it be set up, operated, and maintained at low cost?

Analysis indicates that none of the current methods rates very highly when evaluated by the criteria. The brochure can be made comprehensive, but it then becomes difficult for the passenger to extract information quickly. Updating of brochures to account for frequent schedule, route, and fare changes can be very expensive and confusing to the air passenger. Trained personnel are usually able to respond to a variety of questions. However, the cost of maintaining sufficient personnel to respond to ground transportation questions during peak periods is prohibitive. Space constraints limit the comprehensiveness of signs. A well-designed sign can provide quick information on where to go, whom to call, and perhaps provide more detailed information for downtown trips. However, signs are difficult to update and rarely contain enough information to permit intelligent decision making.

AUTOMATING THE DELIVERY OF INFORMATION

Problems with current information systems point up the need to improve three areas of information delivery:

1. Speed of access,
2. Ease of updating, and
3. Comprehensiveness of information.

These shortcomings could be overcome by taking advantage of the speed and comprehensiveness possible through computer-based automated information systems that are being instituted with increasing frequency in virtually all areas of modern society.

Automated systems are starting to appear at airport terminals. In December 1977, London's Heathrow Airport installed a "route-finder" system that provides subway routing information in three languages for passengers who press a button to indicate their desired destination. Denver's Stapleton Airport has a transit information display board that indicates routes and departure times for all buses that serve the airport (1). These systems provide fast, easily updated, and accurate information for passengers who have already chosen to use transit as a means of getting to their ultimate destination. They do not provide information that would enable a patron to select from a variety of transportation services.

To examine the effectiveness of a more comprehensive system, the Operations Analysis Branch of the Transportation Systems Center (TSC) currently is planning automated ground transportation information systems (AGTIS) at Boston's Logan Airport and Washington, D.C.'s National and Dulles Airports. The work in Boston is sponsored jointly by the Federal Aviation Administration (FAA) and the Urban Mass Transportation Administration (UMTA). The system for the Washington airports is sponsored by the FAA.

BOSTON LOGAN AGTIS

Boston is a logical location for a demonstration of AGTIS because it contains a wide variety of ground transportation services, including bus, limousine, rapid transit, and share-a-cab (a system where reduced taxi fares are charged to patrons who are willing to share a taxi with persons who are going in the same general direction). Boston also experiences frequent heavy traffic congestion in the Sumner and Callahan Tunnels, which connect the airport with most of the metropolitan area and would really benefit from any program that could divert air passengers from low-occupancy to high-occupancy vehicles and rapid transit. The reduction of vehicular traffic to the airport has been given high priority by the airport operator, the Massachusetts Port Authority (Massport) (2).

The heart of the proposed system at Logan Airport is touch-sensitive cathode-ray-tube (CRT) terminals located throughout the airport terminals (Figure 1). A touch-sensitive CRT is recommended because it is easier for an untrained patron to use than the traditional keyboard. The passenger would touch the screen of the terminal and be guided through a sequential series of screen displays to determine the user's local destination and specify the various transportation options that can be used to get to the destination. The sequence is indicated in Figure 2.

The user is asked to select a type of destination, either (a) an area municipality, (b) a landmark (e.g., hotel or university) or (c) another airline terminal at the airport. In the first option, the screen asks a series of questions that the user answers to provide a precise specification of the user's destination zone. When this zone is reached, a service choice display is produced on the screen. If the user specifies a landmark, a service choice display can be referenced directly. Patrons who request another airline are given information on Massport's shuttle bus.

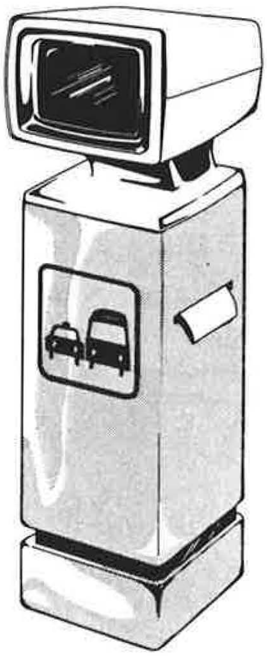
The service choice display indicates a variety of potential means of getting to the destination, including taxicab, share-a-cab, limousine, bus, and rail transit. The information provided for each service is

1. Type of service,
2. Travel time,
3. Service frequency, and
4. Cost.

After reading the service choice display, the user can then touch the screen to receive a detailed service information display for any selected service, including the following:

1. Directions for getting to the point from which the vehicle departs,
2. Name and phone number of the company that provides the service,
3. Fare information,
4. Schedules,
5. Location of stops at destination points,
6. Services available at destination points, and
7. Instructions for use of service.

Figure 1. Conceptual drawing of AGTIS terminal.



The air passenger would receive, if desired, a printed copy of the detailed information to provide a reference during the trip from the airport. The sequence of displays a passenger would go through in the selection of transit service to Cambridge, Massachusetts, is shown in Figure 3.

The system is also intended to provide information on short-term transportation changes and events such as major traffic congestion problems or transit system problems, for example,

1. "Accident in Sumner Tunnel--delays of up to one hour",
2. "Power failure on Blue Line--do not take MBTA transit", or
3. "Hudson Bus Lines reports that its 7:30 a.m. limousine to Concord, New Hampshire, will not depart until 8:10 a.m.".

A functional diagram of the Boston AGTIS is shown in Figure 4. A prototype system, which consists of a touch-screen terminal, printer, and microcomputer with floppy disc storage, has been set up for demonstration at TSC's Cambridge offices.

WASHINGTON AIRPORTS AGTIS

The FAA's metropolitan Washington airports division, operator of National and Dulles Airports, is currently upgrading ground transportation services and considers the automation of the delivery of ground transportation information to be a key part of this program.

A recently completed study of the Washington AGTIS (3) recommended that the Washington airports AGTIS use the data base being developed for Washington, D.C.'s new automated public transportation information system. The Automated Information Directory System (AIDS) will speed up information retrieval for Washington Metropolitan Area Transit Authority (WMATA) staff who answer travel telephone requests for WMATA-operated transit services. WMATA operates rail transit and public buses to National Airport, but the WMATA system does not include airport-based bus or limousine services.

AIDS determines optimal routing information when origin and destination addresses or landmark names

Figure 2. Boston AGTIS flow chart.

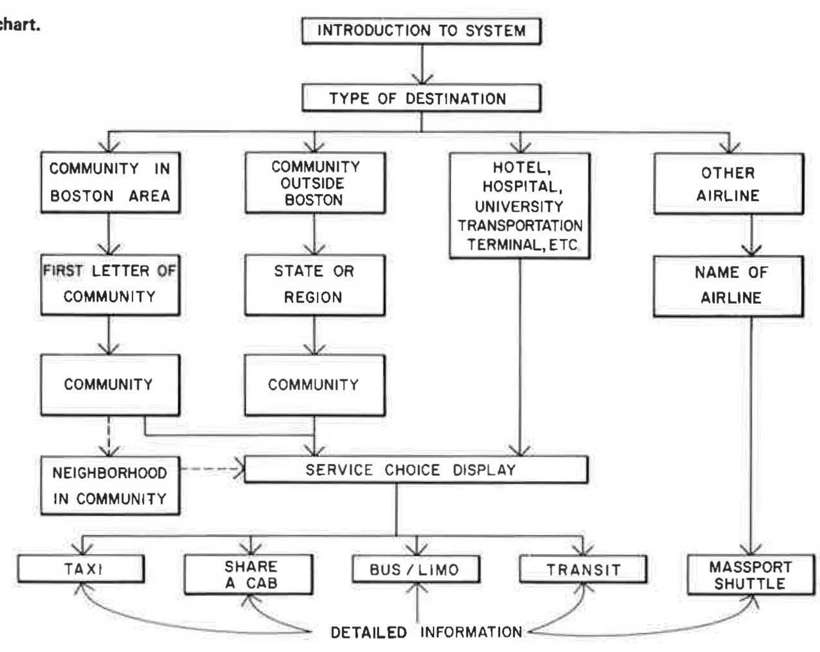


Figure 3. Sample sequence of displays for Boston Logan AGTIS.

WELCOME TO BOSTON

FOR INFORMATION ON TRANSPORTATION
PLEASE TOUCH THE ASTERISKS
BELOW

***

BEM VINDO A BOSTON

PARA INFORMACOES DE TRANSPORTE
MECHA NAS ESTRELAS
EM BAIXO

***

SELECT A DESTINATION OR SERVICE

HOW TO GET TO OTHER AIRLINE TERMINALS (AIR-PORT-SHUTTLE)
*** BOSTON AREA AND MASSACHUSETTS DESTINATIONS ***
SELECTED LOCATIONS IN NEARBY STATES
DOWNTOWN RAIL AND BUS TERMINALS
LIMOUSINE AND BUS SERVICES
MILITARY INSTALLATIONS
UNIVERSITIES
HOSPITALS
HOTELS

TOUCH THE GROUP OF LETTERS CONTAINING THE BEGINNING LETTER OF YOUR DESTINATION

A	M
B	N
C***	O, P
D, E	Q, R
F	S
G, H	T, U, V, W
I, J, K, L	X, Y, Z

SELECT A DESTINATION

CAMBRIDGE	***	CENTRAL AVENUE (MILTON)
CAMPELLO		CENTRAL SQUARE (CAMBRIDGE)
CANTON		CENTRAL SQUARE (E. BOSTON)
CANTON JCT.		CHARLES ST. CIRCLE
CAPEN ST.		CHARLESTOWN
CARLISLE		CHELMSFORD
CARVER		CHELSEA
CEDAR GROVE		CHESTNUT HILL

COMMUNITIES IN CAMBRIDGE

CENTRAL SQUARE		PORTER SQUARE
HARVARD SQUARE		
INMAN SQUARE		
KENDALL SQUARE	***	

KENDALL SQUARE
CHOICE OF TRANSPORTATION

MODE	TRAVEL TIME	COST	AVAILABILITY	MORE INFO
TRANSIT	30 to 40	$ .75	6.00 AM to 11.30 PM	***
TAXI	15	$8.00	on demand	
LIMOUSINE	20 to 46	$3.50	6.30 AM to 11.05 PM	

KENDALL SQUARE
HOW TO GO TO BY TRANSIT
(Available from 6 AM to 11 PM)

TAKE AIR-PORT SHUTTLE BUS TO THE MBTA STATION
TAKE THE INBOUND TRAIN TO GOVERNMENT CENTER
CHANGE TO THE GREEN LINE TO PARK STREET CHANGE TO RED LINE TO ALL POINTS

FOR MIT EXIT AT CENTRAL SQUARE and walk back 1/2 MILE ALONG MASS AVE.

FOR HARVARD U EXIT at HARVARD SQUARE

FOR DOT-TSC EXIT at KENDALL SQUARE

FOR POLAROID EXIT AT KENDALL SQUARE walk about 1/4 mile along MAIN STREET

(NOTE: Have exact change $ .25 ready for airport shuttle)

Figure 4. Boston Logan AGTIS functional system.

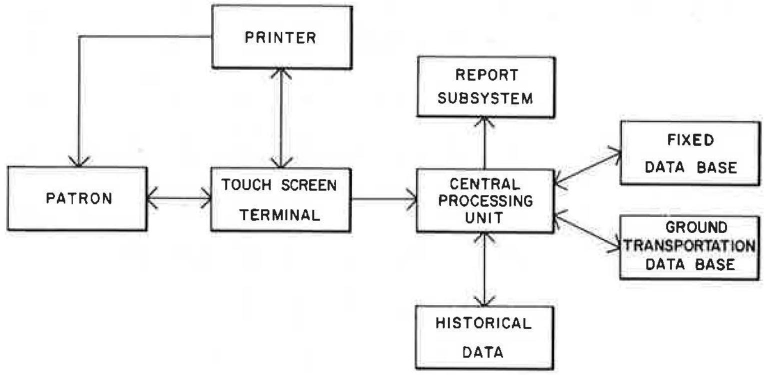
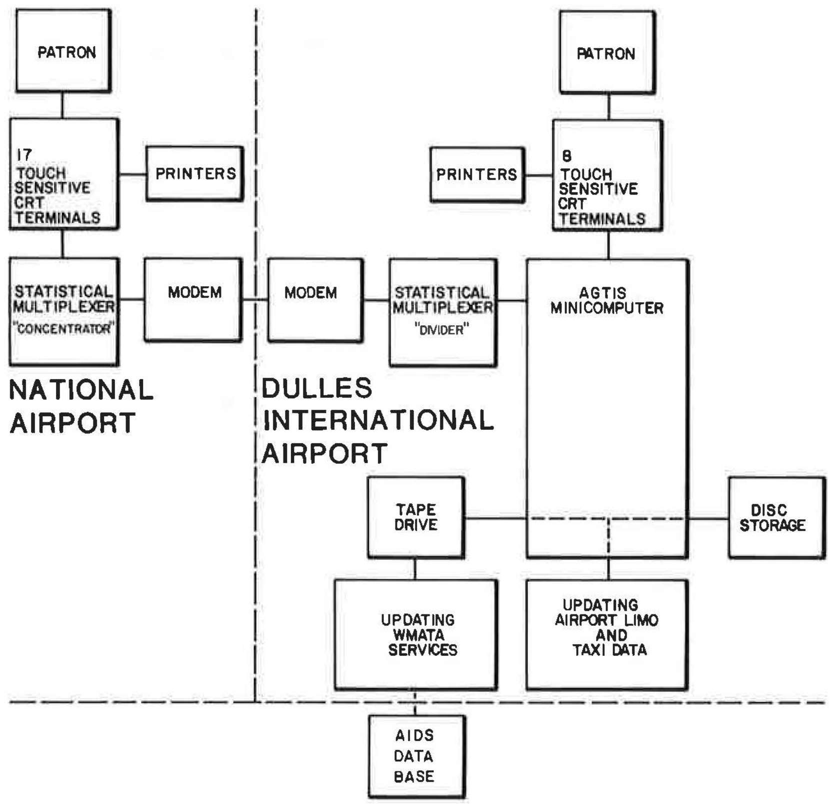


Figure 5. Proposed AGTIS configuration for Washington airports.



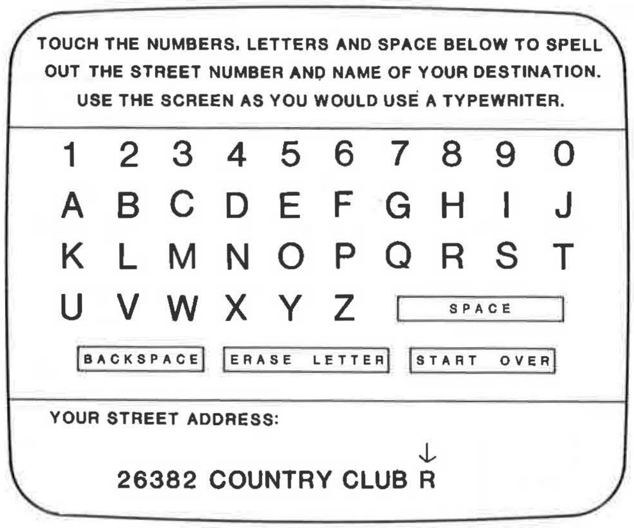
as well as either desired departure or arrival times are known. AIDS is capable of selected optimum routings based on either minimum travel time, minimal number of transfers, lowest cost, or shortest walking distance, depending on the desires of the patron. The two major data files required by AIDS are the geographic and transit files. The geographic data file is essentially a computerized map of the WMATA service area. Given an address, an algorithm developed for AIDS uses this file to generate a set of coordinates. These coordinates are then used to determine routing information. The transit file contains information regarding routes, schedules, and stops for both Metrorail and Metrobus.

AIDS is designed for use by trained WMATA agents, but AGTIS must be available for use by untrained air passengers without assistance. Consequently, a system that uses some features of both AIDS and AGTIS had to be designed.

A proposed system configuration for Washington is shown in Figure 5. Additional study will be required to determine whether it is more cost effective to link terminals at National with a minicomputer at Dulles or have separate computers at both airports. To provide for input of addresses and street intersections on these terminals, an alphabet and number format displayed on the screen is recommended. The patron could spell out a destination by touching the screen, and the address name is displayed on the screen (see Figure 6 for sample).

By using the AIDS data files for WMATA services and new files for taxis and limousines, the AGTIS software would most likely be set up to retrieve transit information that has been preprocessed and stored in a large data file. One way to do this is to generate a grid over the Washington metropolitan area and then relate AIDS destination coordinates to each grid point for WMATA services while predetermining travel distances and times from both airports to each grid point to store taxi information. The portion of the AGTIS data base that consists of WMATA's routes and schedules can be updated as required by duplicating the AIDS route and schedule tape and then running it through the AGTIS central

Figure 6. Possible CRT display for street address input.



processing unit to create an updated AGTIS data file.

EVALUATING THE EFFECTIVENESS OF AGTIS

As a demonstration project, the performance and impact on travel habits of the AGTIS project will be comprehensively examined. Four general aspects of the AGTIS will be evaluated:

1. System reliability and performance--Appraisal of the system's hardware and software components in meeting system specifications and in providing comprehensive and relevant information;
2. System use--Information about the extent of the system use and its usefulness in providing relevant and comprehensive information in an understandable format;
3. System costs--Tabulation of the capital, operating, and maintenance costs so that the system's cost-effectiveness can be assessed; and
4. System effectiveness--Evaluation of the impact of the AGTIS on transit services and on ground travel habits of air passengers.

A program for collecting data at Logan Airport to evaluate all four aspects of the AGTIS is currently being developed. The program (which is only preliminary at this stage) consists of the following ten elements:

1. Air passenger survey--Questionnaire handed out either before or during a sample of departing flights. This survey component is needed primarily to measure change in passenger mode choice and to determine the characteristics of passengers who are not using AGTIS.
2. AGTIS user questionnaire--Distribution of prepaid, mail-back questionnaire survey forms at the AGTIS terminals. The questionnaire would provide a profile of the AGTIS user, including non-air-passenger users of the system, and user perceptions of the AGTIS.
3. Transit carrier questionnaire--Questionnaire mailed to all private bus and limousine operators who provide service at Logan Airport to assess the AGTIS' impact on carrier operations and on the availability and further need for other transportation mechanisms employed by the carriers.
4. Massport interview--Interview to determine Massport's perspective on the feasibility and effectiveness of the AGTIS demonstration at Logan Airport. The interview would focus in on system reliability, user acceptance, impact on Massport's operations and costs, and suggestions for other airports.
5. Rapid transit rider count--Count riders who enter and leave the Massachusetts Bay Transportation Airport Station for one day both before and after AGTIS implementation to assess AGTIS impact on rapid transit.
6. Internal roadway count--Traffic counts conducted at selected roadway locations to measure AGTIS impact on vehicular traffic. The counts would be taken during the duration of both air passenger survey periods (seven days each).
7. System observations--Observations of persons who use AGTIS will provide information on system comprehensibility and human factors problems. Data received from these observations will be used to correct the AGTIS data base and procedures as well as evaluate the system.
8. AGTIS maintenance records and operator logs--System records will be used to provide an objective record of system performance throughout the life of the project. Maintenance records would be prepared for every preventive maintenance, failure, or malfunction observed.
9. AGTIS data files--AGTIS user tabulations will be compiled by using an AGTIS Report Generator subsystem that will summarize data stored in the historical data files on patron use. These data will be used to provide general information concerning system use and to provide base data for comparison with the air passenger and AGTIS user surveys.
10. Massport records--Ridership data currently collected by Massport for limousine, private bus, taxi, and share-a-cab services on a monthly basis will be summarized by the contractor for a period of time before and after AGTIS implementation. These data will identify long-term trends in public transporation use and verify results obtained from the air passenger surveys.

CONCLUSIONS AND FUTURE APPLICATIONS

Computer systems are becoming less expensive and more powerful while costs are rising in virtually all other areas. An automated information system may be one of the least costly means of increasing transit ridership (although this assumption has not yet been tested) and therefore decrease traffic congestion and energy costs. If the system proves successful, it could be applied to major rail and bus transportation terminals as well as airports.

ACKNOWLEDGMENT

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Airport Access: Case Study of a Remote Terminal Operation

MARGORIE KAPLAN

Interest has developed in recent years in remote airport terminals as a means of reducing landside congestion at metropolitan airports. A prime consideration in assessing the suitability of the remote terminal concept for a particular airport lies in its economic feasibility (i.e., Can it attract sufficient patronage and be operated efficiently enough to be cost effective?). This paper analyzes the costs of operating the FlyAway bus system, an express bus service that links Los Angeles International Airport with a suburban area that contributes about 15 percent of the airport's passengers. Although it does not offer baggage check-in, other services, such as ticketing, are offered on a limited basis and expansion to a full-service remote terminal is a distinct possibility in the future. The objective is to identify actual costs relative to all aspects of the operation to assist planners in determining the costs of such systems for other airports. Included are overviews of physical characteristics, operational problems, passenger market segment, airport and bus patronage growth rates, cost-revenue ratios of bus operation and terminal maintenance, bus fuel price impacts, foregone bus terminal site rental income, break-even patronage, facility replacement costs, and prognosis for future activity. After five years of operation, many of them beset with problems, FlyAway appears to be thriving. A recent passenger survey revealed that much of the system's attractiveness lies in its economical fare, frequent headways, low-cost parking, and dependable service. As passenger volumes rise and roadway capacity continues to be stretched beyond design standards, remote terminals offer the best hope for alleviating airport congestion on the ground. FlyAway demonstrates that, not only do they work, but they work well and cost effectively.

Enthusiasm for new rail systems for express ground transportation service to airports has been dampened by mechanical malfunctions, design inadequacies, and the high capital expenditure associated with building and operating such systems. Therefore, many airport operators are turning to express bus services as an alternative to expensive (in terms of cost and land use) roadway and parking lot expansion. Express buses have a number of decided advantages over other forms of transit:

1. Buses are relatively affordable, they generally cost about $120 000 for standard models;
2. Buses are dependable and durable, the art of bus design and construction is rather advanced;
3. Buses require minimal start-up time for initiating service because buses generally require no special roadway adaptation or elaborate driver training;
4. Buses may be disposed of readily if a system is unsuccessful in attracting patrons because there is a large market for used buses in the United States; and
5. Buses are adaptable in route selection because they are free moving and are not bound to fixed guideways.

Given all these positive characteristics and an awareness that the ground access network at Los Angeles International Airport would soon be inadequate if forecasts of passenger demand were accurate, the Los Angeles Department of Airports inaugurated the FlyAway bus service on July 10, 1975. FlyAway was a pilot express bus service designed to provide residents of the San Fernando Valley--a large sprawling suburban community located 20 miles (32.2 km) north of the airport--with a direct bus line to Los Angeles International Airport. The motives for creating this service included the following (1):

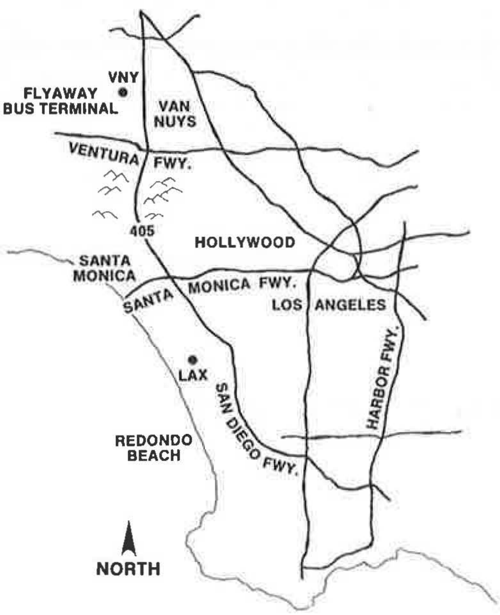
1. Establish a pilot program to study the effectiveness of the remote terminal concept;
2. Alleviate curb-side and parking lot congestion at the airport;
3. Alleviate airport, roadway, and freeway vehicular congestion (2);
4. Conserve energy; and
5. Reduce air pollution.

Most importantly, given the prevailing ground access modal split of 90-10 for private automobile versus bus or limousine transport (3), the airport's central terminal area roadway had a passenger capacity of approximately 28 million passengers annually, which is well below the capacity of the runways and terminal buildings. Consequently, the primary physical constraint to growth at Los Angeles International Airport was ground access capacity.

This problem was due not to faulty design but rather to optimistic planning: The airport had been built under the assumption that a complete freeway network would encircle it and bring traffic from all directions. A set of underground tunnels had also been planned to channel traffic from airport environs directly into roadways and parking lots at the western end of the terminal area loop (4). These improvements were supposed to eliminate bottlenecking at the airport's main entrance, reduce queueing at the curb sides, and relieve congestion on the interior roadway.

Unfortunately, because the extreme high passenger volumes predicted for the late 1960s failed to

Figure 1. Los Angeles International Airport-Van Nuys Airport access route.



materialize on schedule and the flat-growth period of the early 1970s set in, the previously described highway, roadway, and tunnel support system was reduced in concept. Ultimately, slow growth was followed by the 1974-1975 recession, and the support system was tabled indefinitely.

Today, the ground access system that serves Los Angeles International Airport remains virtually the same as when the airport was developed in 1961 (5). It consists of one major freeway that runs north-south (Interstate-405) plus several primary surface streets, including one that feeds from I-405 directly into the airport's central terminal loop. The loop is a U-shaped one-way circulation system; the terminal buildings ring the outer edge and the parking lots and structures are in the middle. The roadway is now capable of handling about 30 million passengers annually at service level D. In 1979, Los Angeles International Airport served nearly 35 million passengers. The FlyAway bus was an experiment to address this imbalance in supply and demand of ground access capacity.

FlyAway, a relative pioneer in the remote terminal arena, has attracted much attention as landside constraints at metropolitan airports point to remote terminals as a tactic for relieving congestion. Though originally conceived as a full-service remote terminal, airline baggage check-in has not yet been implemented and airline ticketing is provided on a limited basis only. Both services may be provided, pending airline support, in the future. This paper describes and discusses the costs of the FlyAway bus service. The purpose of this discussion is to provide background to help airport planners evaluate the economic feasibility of remote terminals.

NEW SYSTEM'S GROWING PAINS

The San Fernando Valley was a prime location for such an airport express bus service. It is located a reasonable distance away (about 20 miles) via a mountain pass that has only two primary access routes to the airport (Sepulveda Boulevard and I-405), it houses a large sprawling bedroom community that contributes about 15 percent to Los Angeles International Airport's total passenger market, and the department of airports owns a large piece of real estate at a central valley location. This real estate, better known as Van Nuys Airport (a large general aviation facility), meant that the department of airports could initiate its program without buying, leasing, or paying taxes on land (see Figure 1). In addition, an existing building was available at Van Nuys that could be adapted for use as a bus terminal, and it was adjacent to a large parcel that was suitable for a 1400-space parking lot. The site totaled 12.2 acres (4.94 hm^2).

As a result of recommendations contained in a feasibility study completed in 1973 by Wilbur Smith and Associates, the FlyAway bus service was inaugurated in mid-1975. It operated via six department-owned Neoplan buses, made a circuit of 44 scheduled round trips/day, and had 30-min headways in the daytime and 75-min headways between 12:30 and 5:30 a.m. The adult fare was $5 round trip or $3 one way, child's fare was $1.50 each way, and employee passbooks were available to all persons who worked in any capacity at or near the airport. Parking was available at the Van Nuys terminal for $0.50/lot entry, and no limit was placed on parking duration.

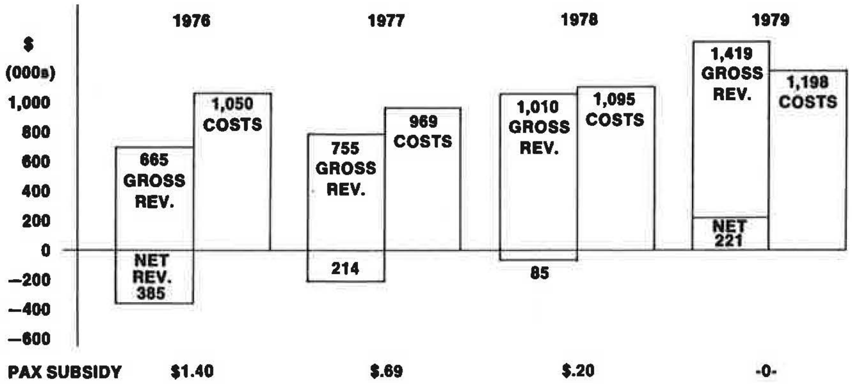
Although the feasibility study had addressed the possibility of the FlyAway being a full-service remote terminal that included airline ticketing and baggage check-in, the additional expense of such a service plus airline opposition to remote baggage check-in made it unsuitable for the pilot program.

By the end of December 1975 the system had carried nearly 90 000 passengers and collected $225 843 in passenger fares plus $7239 in parking fees (total = $233 982). Costs for bus operation were $464 510, which left an operating deficit of $231 428. Since the service was new, an initial deficit had been anticipated; however, it was hoped that the service would be in the black within two years.

OPERATIONAL PROBLEMS

Such expectations seemed realistic. From the onset, patronage was much stronger than had been projected in the FlyAway feasibility study, and it continued to grow steadily. In August 1976, the entry fee to the parking lot was raised to $1, which caused no apparent change in patronage of the parking lot. A break in the growth pattern came in late 1976, when Airport Transit, the company under contract with the department to maintain and operate the buses, folded. This cut off service abruptly and tied up the department's buses in a legal tangle. The Neoplan buses were put into storage pending a decision as to their status, and bus service was suspended for three days until a new company could be hired to resume service by using its own buses. At this point, FlyAway began operating under a series of short-term agreements while legal matters were settled and a new, comprehensive contract negotiated. The Associated Charter Bus Company took over the service on December 23, 1976, and ran it until July 6, 1977, at which time FlyAway was taken over by Grayline Tours. Grayline ran the service until November 7, 1977, when the Associated Charter Bus Company was awarded a one-year contract for bus operation and maintenance issued through the department's standard bid procedure. Associated's contract ran until November 8, 1978. The company planned to phase out bus service operations and did not rebid for the service when its contract expired. Through the bid process and negotiations, the service was then contracted to Grayline for a three-year term plus a two-year option, with a stipulation that seven new buses be purchased. This

Figure 2. Summary of FlyAway Bus system activity.



contract is still current and will remain in effect until November 8, 1981, and may be extended to 1983 if the options are exercised.

COST-REVENUE RELATIONSHIP

The terms of the contract specify one inclusive hourly cost that includes bus operation and purchase, maintenance, and all overhead. These items had previously been billed separately. The hourly costs are $22.25 for the first year of the contract, $23 for the second year, and $24.50 for the third year. The contract stipulates that hourly cost covers the period beginning when a bus arrives at the Van Nuys terminal and ending when the last passenger is dropped off, including any layover (deadhead) time.

The contract also has an escalation clause to cover possible increases in fuel price. The clause stipulates that, for every $0.03 increase in bus fuel prices, the hourly operations cost will increase by $0.15. This clause has been an active factor in the bus operation's costs because the price of fuel has fluctuated greatly (see table below).

Date	Fuel Price ($)	Hourly Rate ($)
12/78	0.48	22.25
3/79	0.48	22.25
6/79	0.57	22.70
9/79	0.754	23.60
12/79	0.79	24.50
3/80	0.86	24.80
6/80	0.952	25.25
9/80	0.952	25.25
12/80	0.963	25.40

At an average of 34 000 bus service hours/year, the increase in fuel prices added approximately $55 000 to the cost of the service between November 1978 and June 1980 ($15 000 for the first year of the current contract period and $40 000 for the first eight months of the second year).

At the end of the three-year contract period Grayline has the option to continue operating the service for an additional two years. They would apply the Los Angeles-Long Beach consumer price index (CPI) to the hourly base of the previous year to compute each new yearly rate.

Despite periodic and, at times, severe fluctuations in level of service until the end of 1978, when the current contract was enacted, patronage of the FlyAway remained high on an annual basis and reached a peak in 1979. A summary of FlyAway economic activity and passenger subsidy is itemized in Figure 2.

These figures are difficult to compare as a cohesive series because the various bus operators that ran the service charged different hourly fees. For example, for bus operation (excluding bus maintenance and terminal operation) the rates in Table 1 were applied. The apparently large difference in hourly rates is due to differences in hourly pay scales for bus drivers as well as administrative costs. Hourly bus driver wages have varied between about $5.50 and $8.50 per hour (nonunion versus union, respectively) for private operators in the southern California area. The cheaper service had a lower service level, frequent personnel problems, and frequent bus breakdowns. There was a noticeable relation between level of service and patronage during 1976 and 1977, when the service changed management frequently. Patronage would fall off when the service became irregular, unreliable, or unfriendly and then would revive slowly when such problems were corrected. In addition, monthly payments of $15 862.12 to United California Bank for lease and payment of the Neoplan buses were suspended when the buses went into storage in December 1976. These payments were resumed at $17 137.45 in July 1977 and were paid until November 1978, when the Neoplan buses were retired from FlyAway use. The suspension of payments reduced the system's cost by about $100 000 in 1977.

A more detailed breakdown of the system's costs is provided in Table 2. When deflated by the CPI for public transportation in the Los Angeles-Long Beach standard metropolitan statistical area (SMSA), the yearly costs convert to $795 981, $656 708, $723 823, and $728 106 for the years 1976-1979.

Additional personnel and a restructuring of the accounting system account for the large differences in cost for certain items between 1977 and 1979. Terminal staffing as of 1979 included six clerk positions, five security personnel (some were part

Table 1. Operational rates per company.

Year	Company	Service Period	Hourly Rate ($)
1976	Airport Transit	1/01-11/30	14.58
	No service	12/01-12/02	
	Grayline	12/03-12/22	21.75
	Associated	12/23-12/31	14.15
1977	Associated	1/01-7/06	14.15
	Grayline	7/07-11/07	21.75
	Associated	11/08-12/31	14.15
1978	Associated	1/01-11/07	14.15
	Grayline[a]	11/08-12/31	22.25
1979	Grayline	1/01-11/07	23.00
		11/08-12/31	24.50
1980	Grayline	1/01-11/07	24.50

[a]Start of three-year contract.

Table 2. FlyAway Bus operational costs.

Item	Operational Cost ($000s) 1976	1977	1978	1979
Security	49.3	53.5	64.5	63.3
Grounds and parking lot	21.4	20.3	30.0	28.3
Terminal maintenance and administration	22.2	48.6	85.1	110.4
Wages and fringes	57.8	65.1	86.0	81.2
Bus operations and maintenance	564.8	550.9	611.7	869.2
Neoplan payments	174.5	137.2	154.3	0
Advertising	157.4	89.1	52.7	36.1
Miscellaneous	2.3	4.5	10.8	9.2
Total	1049.7	969.2	1095.1	1197.7

time), and one supervisor. The high publicity costs in 1976 were generated by an intense campaign to popularize the system. An annual average pay adjustment of +5.6 percent is also reflected in these costs.

As shown in these figures, most items are fixed-cost items. The largest and most essential item was bus operation and maintenance. There is every reason to assume that these items will remain relatively stable over the next few years, with adjustments for inflation and fuel prices. A simplified break-even analysis of the bus system for 1979, the first year it was in the black, produced the relationship shown in Figure 3. Break-even analysis is a method of relating fixed costs, variable costs, and total revenues to show the level of sales that must be attained if the system is to be self-supporting or operate at a profit. The variable costs in the FlyAway analysis included advertising, general administration, and miscellaneous. Also, it was assumed that the proportions or types of tickets sold and the ratio of tickets sold to parking lot use would remain constant.

As is the case with operations that have high overhead, FlyAway's break-even point requires high income; but FlyAway has the potential for a substantial rise in revenue as passenger volumes increase, due to the high degree of operating leverage. This characteristic is even more pronounced in the case of a hypothetical fare increase, as shown in Figure 4. In this instance, a 30 percent price increase was applied, which resulted in much lower passenger volume needed to reach the break-even point and an even higher revenue potential. Since the FlyAway fare prices have remained stable in nominal terms since the service began in 1975, a 30 percent increase is not unreasonable. If deflated by the CPI for transportation in the Los Angeles-Long Beach-Anaheim area over the four-year period, the real bus ticket price is more than 30 percent less than the nominal price.

The prices applicable to the two analyses are as follows:

Item	Price ($) Figure 3	Figure 4
Adult round trip	5	6.50
Adult one way	3	4
Child	1.50	2
Employee passbook per 20 round trips	35	45

Parking was held constant at $1 per entry and each stay was limited to 15 days.

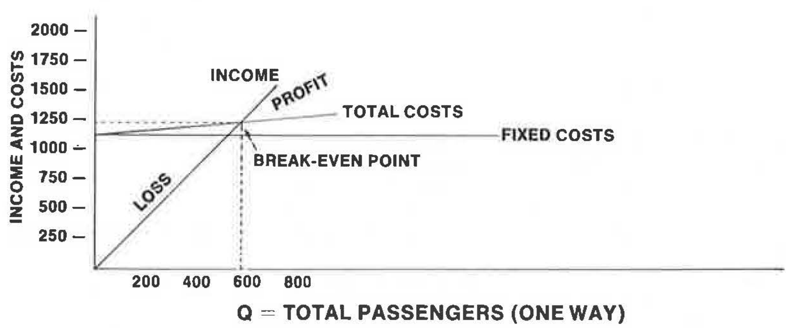
Given that parking in the Los Angeles International Airport central terminal area is $10/day or $1.50-$2/day in Los Angeles International Airport peripheral parking lots and applying a moderate $0.25/mile cost to driving a car, the 40-mile round-trip ride to Los Angeles International Airport from the valley would cost a minimum of $10 for driving expense plus an additional amount for parking. At an average parking duration of five days for the FlyAway lot, the least-expensive travel and parking for five days for a private automobile from the valley is $17.50 ($10 to drive + $7.50 to park at $1.50/day). Clearly, even at the 30 percent higher rate, the FlyAway would still be a bargain.

REPLACEMENT COSTS

An additional element in this cost analysis is a review of facility construction costs and foregone ground rental income at Van Nuys Airport. In December 1977, the use of the Van Nuys site for FlyAway was reviewed and a proposal to relocate the bus terminal was evaluated.

At that time only 3340 ft² (310.62 m²) of the 6530-ft² (607.29-m²) terminal building were

Figure 3. Break-even analysis under 1979 rate structure.



Q	VARIABLE COSTS	FIXED COSTS	TOTAL COSTS	SALES	NET PROFIT
678 000	125 000	1 080 000	1 205 000	1 420 000	215 000
800 000	147 500	1 080 000	1 227 500	1 672 000	444 500

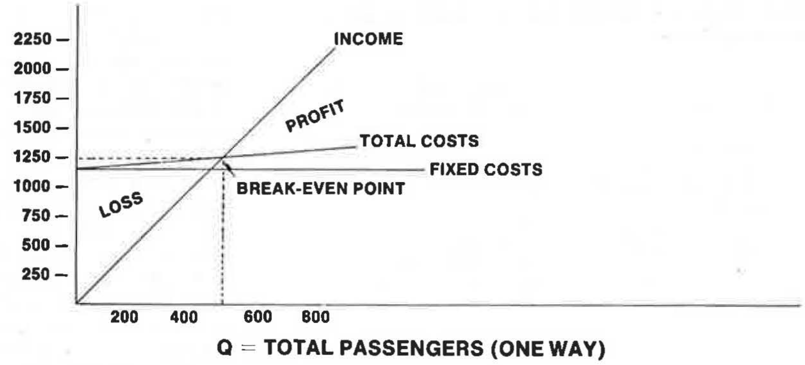
$$\text{Break-even} = \frac{\text{Fixed costs}}{1 - \frac{\text{variable costs}}{\text{sales volume}}} = \frac{FC}{1 - \frac{VC}{P.Q}}$$

variable cost = .1842 Q

average price = $2.09

$$BE = \frac{1\ 080\ 000}{.911786} = \$1\ 184\ 488 \text{ in sales} = 566\ 740 \text{ pax}$$

Figure 4. Break-even analysis by using 1979 rate structure adjusted for inflation.



Q	VARIABLE COSTS	FIXED COSTS	TOTAL COSTS	SALES	NET PROFIT
678 000	125 000	1 080 000	1 205 000	1 820 565	615 565
800 000	147 500	1 080 000	1 227 500	2 152 000	924 500

variable cost = .1843 Q

average price = $2.69

$$\text{B.E.} = \frac{1\,080\,000}{.931} = \$1\,159\,467 \text{ in sales} = 431\,029 \text{ pax}$$

Table 3. FlyAway Bus ridership.

	One-Way Ridership							
	1976		1977		1978		1979	
Fare Type	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Full-fare passenger	215 398	78	240 736	78	326 371	79	508 166	75
Half-fare passenger	11 927	4	13 064	4	17 419	4	27 106	4
Employee passbook	45 880	17	54 246	17	62 364	15	128 735	19
Other	1 899	1	2 669	1	9 605	2	13 551	2
Total	275 104		310 715		415 759		677 554	

being used, and 1400 parking spaces were in use on the 12.2 acre (4.94 hm^2) site. It was estimated that construction of a new 3340 ft^2 terminal that had a 1400-space parking lot would cost about $1 million in 1979 dollars. This included cost estimates of about $485/parking space plus $100/$ft^2$ for the building. Replacement with a 6530-ft^2 building and an 1800-space lot added to more than $1.5 million.

These costs, when compared with the potential ground rental income of $7225/acre per year on the industrially zoned site ($88 145 annually) did not justify relocation of the terminal. Shortly thereafter, the lot was expanded to approximately 1800 spaces and an additional 3.3 acres (1.34 hm^2) were added to the parking lot. Even when the lost rental income became $111 988/year for the 15.5 acre (6.28 hm^2) site, this was still lower than the amortized cost over a 30-year period of building a replacement facility (estimated at nearly $150 000/year).

PATRONAGE

A review of bus passenger ticket activity reveals the breakdown in Table 3. This breakdown shows a constant distribution of types of bus users over time, with a substantial portion of patronage coming from the airport and airline employee sector.

A closer look at the FlyAway market was taken by the department of airports in 1979 via a survey questionnaire handed out and collected on the buses. Questionnaires were collected over a one-week period in April and another week in August, the peak travel month. The April survey, which had 1983 valid responses, was completed just before the gasoline shortage of that year, and the August survey, which had 666 responses, was intended to hit the peak vacation travel period. Not surprisingly, the responses to the surveys were differentiated by a slightly higher proportion of recreational travelers in the August run. Consequently, the following shifts in passenger market were expressed:

Item	April 1979 (%)	August 1979 (%)
Passenger traveling alone	54.6	45.0
Passenger traveling with spouse	24.0	32.8
Female head of household		
Working outside the home full time	34.2	42.9
Not working	38.3	30.4
Male	62.2	59.9
Female	37.8	40.1
Business trip	46.1	39.9
Vacation or personal trip	47.2	55.6

The remaining market characteristics remained constant. The most relevant ones to this discussion were cross-tabulated and were drawn from the April survey. These include characteristics of modal choice, income, business versus nonbusiness travel, number of trips per year, access travel time, and bus terminal parking characteristics. These data reveal that FlyAway's passengers come from a high-income pool (85 percent earn more than $30 000/year), are frequent travelers (40 percent take more than 5 business trips/year), are well educated (47 percent are college graduates or postgraduates), are predominantly more than 30 years old (67 percent are in the 30-59 year old group), started out to the bus terminal from their residence or the home of a friend (92 percent), and often drive a considerable

Table 4. Comparison of passenger volumes: FlyAway Bus terminal versus Los Angeles International Airport.

	FlyAway Passengers			Los Angeles International Airport Passengers	
Year	Number	Annual Growth Rate (%)	Market Share (%)	Number	Annual Growth Rate (%)
1976	275 104		10.1	25 983 079	
1977	310 751	12.9	10.4	28 361 836	9.2
1978	415 759	33.8	12	32 901 361	16
1979	677 554	63	18.5	34 923 205	6.1

time to get to the bus terminal (42 percent drove 6-15 min, 37 percent drove 16-30 min, and 10 percent drove 31-45 min). FlyAway's travel time to Los Angeles International Airport from the valley terminal ranges from 30 min under free-flow conditions, to more than an hour during peak periods.

GROWTH RATES OF PASSENGER VOLUMES

When viewed in terms of Los Angeles International Airport passenger volumes, FlyAway has managed to capture a considerable portion of market share. This is illustrated in Table 4.

The market share is calculated by subtracting the 25 percent of Los Angeles International Airport passenger volume that is connecting traffic and then assuming that, of the remainder, 14 percent is currently based in the San Fernando Valley. [The valley's market share has declined from 15 percent in 1975 due to rapid growth in the passenger market located in Orange County (6).]

PLANNED IMPROVEMENTS AT LOS ANGELES INTERNATIONAL AIRPORT

The department of airports currently has a goal of building two major new terminals, three parking structures, and at least one phase of a double deck for the central terminal roadway before the 1984 Olympics. These improvements promise to create serious access problems during the several years of construction. Systems such as FlyAway offer the only hope for serving growing passenger volumes while roadway capacity is curtailed. In addition, when the second-level roadway is completed, special lanes will be provided for buses on the lower level, thereby more specialized service will be offered for bus passengers. In conjunction with this plan, the regional transportation plan specifies that special lanes for high-occupancy vehicles be provided whenever feasible (7). Such lanes are currently being planned for the freeways that access Los Angeles International Airport. If this system can be coordinated and implemented, remote terminals will clearly become increasingly attractive to passengers, employees, and airport operators.

If the FlyAway experience is at all typical of what a metropolitan remote terminal can do, the good news is that not only can such a system be useful and attract considerable patronage, it may also operate without subsidy.

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Airport Geometric Compatibility of Future Aircraft

BARRY R. HOY

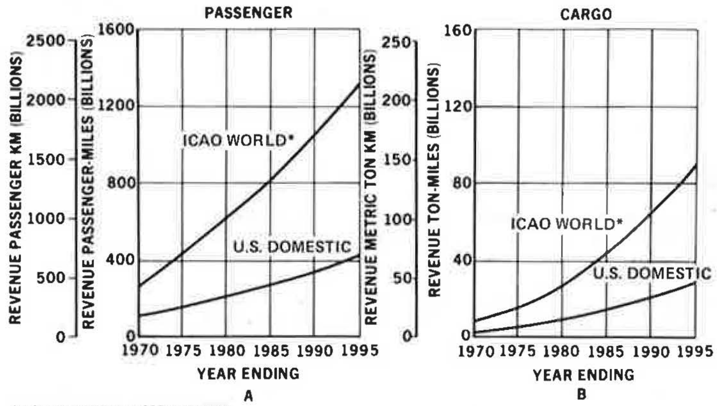
Capacity limitations at many of the major hub airports restrict the ability of carriers to add flights to accommodate increased demand. Increases in seating densities on existing aircraft will reach marginal comfort limits, and therefore, the demand can only be handled by the upgrading of existing airports, building of new airports, or the use of aircraft that have higher seating capacities. The last solution would impose greater operating and physical limitations on the airport system. The ability to physically expand airports and build new ones is subject to environmental and fiscal constraints and land availability and has proven to be almost impossible. Therefore, future growth will require the use of a greater percentage of aircraft that have large seating capacities. This paper analyzes the characteristics of wingspan and existing runway and taxiway separations at 31 hub airports. The effects of these characteristics are evaluated as a function of current airport runway and taxiway systems. The data and conclusions may be used to develop a technical rationale for accurate measurement of necessary separations and to help evaluate the adequacy of current airport standards as more large aircraft are accommodated in the future.

The possible construction of any new U.S. airports within this century is remote; however, air transportation is a rapidly growing industry (Figure 1) that seems to continually exceed planned capacities. The major aircraft manufacturers are receiving strong pressure from two sides:

1. The stressed operating environment, which requires more large aircraft to satisfy the continual increase in demand and relieve capacity problems, and
2. The difficulty in changing existing airports to meet the requirements of the large aircraft, as well as the lack of support by authorities for such changes.

The introduction of the wide-bodied aircraft

Figure 1. Future growth trends.



*NOT INCLUDING USSR AND PRC

REF CTOL TRANSPORT AIRCRAFT CHARACTERISTICS, TRENDS, AND GROWTH PROJECTIONS, JANUARY 1979

(e.g., DC-10, L-1011, and B747) brought initial compatibility problems to many airports because these aircraft were revolutionary in size and higher off the ground than their predecessors. Fortunately for the aviation industry, land was available for expansion of both airside and ramp areas. The cost of these airfield modifications and development of needed ground support equipment was the price paid for the increased productivity and preferred environmental factors of the wide-bodied aircraft. At present, however, the capability for unlimited airport expansion no longer exists and, because choices of alternative airport sites are very limited, increased dimensions for aircraft become exceptionally critical. Promotion of a larger wingspan is a prime example.

This paper assumes that the goal is to have unrestricted, maximum runway capacity during routine daily operations. Therefore, the airside system, runways, taxiways, and maneuvering procedures should reflect a design to accommodate this capacity. Visual meteorological conditions (VMC) and instrument meteorological conditions (IMC), the two weather operational criteria, play an important role in airport capacity and, consequently, aircraft sizing. IMC operations require relatively large landing sequences, but maximum airfield capacity is always achieved during VMC operations; therefore, IMC operations are not thought of as being significant relative to aircraft sizing as are VMC operations. Thus, IMC separation minimums are not discussed.

FUTURE AIRCRAFT TRENDS

Prediction of future trends in aircraft design is a required function of airport planning. Without trend forecasts, planners would be forced to design future airports around existing aircraft dimensions. Usually, the process from initial planning to end of construction before an airport becomes operational takes 10-20 years, and a master plan for the airport's future is designed for staged construction during the first 20 years of airport operation. Therefore, a good forecast, capable of meeting the needs for airport planning, should project a period of 30 years. At present, such a forecast has not been developed; however, the Aerospace Industries Association of America (1) published the following forecast of maximum aircraft dimensions for the period through 1995 (note: 1 m = 3.28 ft; 1 kg = 2.20 lb):

Item	Dimension
Wingspan (m)	Up to 84
Outer main gear wheel span (m)	Up to 20
Overall length (m)	Up to 84
Tail height (m)	Up to 23
Maximum gross weight (kg)	Up to 567 000

Douglas is currently projecting a more modest wingspan increase of 10-17 percent over present lengths. This percentage growth is based on general opinions expressed by the airlines to manufacturers as to their liability responsibilities (e.g., insurance premiums) and on apparent public lack of enthusiasm for giant aircraft that have seating capacities significantly higher than those of the B747. Thus, an increase in the present 60-m (196-ft) wingspan maximum could progress to a future possibility of 70 m (230 ft). The 70-m projection is used as the basis for this paper and, although a serious problem at several main hub airports, is speculated as compatible in most present airport systems.

Standards

Newly configured aircraft will operate in today's airports with minimum change in the location of airport components and, it is hoped, without further reduction of airport capacity. However, aircraft dimensions that are much larger than the Boeing B747 will challenge these airports in their present configurations. Therefore, the question remains, Just how large an aircraft will be compatible with a majority of present airport systems?

The general consensus is that the airside geometry of an airport is the most-critical, least-changeable part of the airfield's system, regardless of cost. This is due mainly to environmental considerations. Therefore, this paper is concerned with the runway and taxiway system (an apparent limited part of the airside geometry) and its relationship with wingspan dimensions.

The compatibility of an aircraft with its ground environment depends on interrelated aircraft and airport features, all of which must be considered by the design engineer. Each major airside component represents an interface with one or more aircraft features. Since airports are built to accommodate aircraft and ground vehicle modes to accomplish their interchange, it would be logical to have a system of airports designed scientifically in terms of related aircraft parameters. However, this is not the case in many airport standards. These standards are frequently based on experience and are revised, as necessary, to meet changing aircraft requirements. Figure 2 illustrates Federal Aviation

Figure 2. FAA airport components.

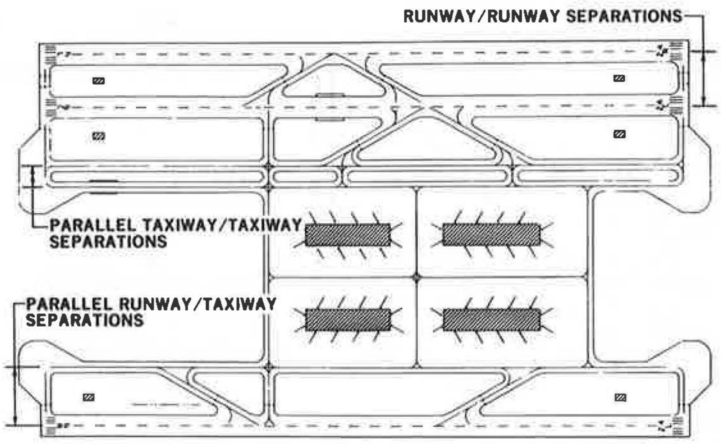


Table 1. Summary of recommended airport standards.

Item	Recommended FAA Standards (m) Design Group 2	Design Group 3	Design Group 4	Recommended ICAO Standards (m) Runway Code Letter A
Runway width	45.7	61		45.7
Taxiway width	23	23	30.5	23
Taxiway-taxiway separation[a]	91.5	91.5	110	85.4
Runway-runway separation[a]	305	366[b], 427[c], 854[d]		213.4
Runway-taxiway separation[a]	122	122	183	186.5

Note: 1 m = 3.28 ft.
[a]Visual flight rules.
[b]Maximum capacity.
[c]Opposite direction, day.
[d]Opposite direction, night.

Administration (FAA) airport components of a runway and taxiway system that are interrelated with aircraft parameters. These parallel components, runways, and taxiways are of immediate concern to this paper.

Since the United States is a member of International Civil Aviation Organization (ICAO), both the international specifications and domestic FAA standards must be considered. Table 1 summarizes the FAA and ICAO airport component sizes that are represented by standards of recommendations.

Aircraft and Airport Parameters

Airport component sizes advocated by the FAA and ICAO, although different, are based on traditionally accepted values and long-standing practices of safe operations. Past studies have revealed no clear evidence that these component sizes are too large or minimally safe or that their potential impact on the future system could be pervasive.

The most critical issues to wingspan and overall fuselage length are runway and taxiway system centerline separation criteria because of the inability to physically relocate either element in order to gain additional clearance distance (i.e., parallel runway, parallel runway and taxiway, and parallel taxiway separation distances). The recommended separation minimums in Table 1 address these issues.

Note that design group 4, as shown in Table 1 for requirements for aircraft larger than a B747, has several undefined areas as a result of unknown aircraft dimensions. This paper should encourage definition of these undetermined areas.

History provides us with a number of lessons. For example, FAA, in its original airfield geometrical and structural pavement-width standards for the three- and four-engined wide-body aircraft included these aircraft exclusively in a design group 3 category. Concurrently, FAA established and promoted dimensions of 30 m (100 ft) and 61 m (200 ft) for structural taxiway pavement width and optimum structural runway pavement width, respectively, for design group 3. However, subsequent actions of the FAA

1. Dropped the DC-10 and L-1011 into design group 2 (2, change 1),
2. Reduced the taxiway pavement width to 23 m (75 ft) (2, change 2) and set the minimum runway pavement width at 46 m (150 ft) with appropriate shoulders for design group 3, and
3. Made compensating adjustments to other taxiway dimensional criteria.

These changes were prompted by actual operational experience that indicated that these wide-body aircraft operators had already constructed facilities to the original standards or had engineering plans ready for implementation. The construction may have long-term payoffs but the added capital and interest might have been put to better use elsewhere.

In order to present an accurate picture of existing separations at major hub airports, 31 worldwide airports were selected for their large traffic volumes and varying airside layouts (see Table 2). A present separation analysis of each data-base airport is shown in Figures 3-5; all make reference to FAA-recommended minimums. As shown in Figures 3-5, several major hub airports are already experiencing pressure because of the separation minimums recommended for the 60-m (196-ft) wingspan of the B747 and, therefore, offer very limited capability to accommodate wingspans of greater dimensions comfortably.

EVALUATING AIRPORT RUNWAY AND TAXIWAY SYSTEMS

Conclusive evidence of possible reductions in recommended airside separation minimums to accommodate larger aircraft is difficult to obtain. This is mainly caused by a lack of technical rationale. In the evaluation of airport runway and taxiway systems it is important to not attempt to set a goal of reaching a total solution for airport limitations but rather to develop a basic method that permits more existing airports to become compatible.

Conservatism in separation minimums is herein

Table 2. Data-base airports.

Airport	Location	Airport	Location
Schiphol	Amsterdam, Netherlands	Los Angeles International	Los Angeles, CA
Athinai International	Athens, Greece	Barajas	Madrid, Spain
Hartsville International	Atlanta, GA	Dorval International	Montreal, Canada
Bangkok International	Bangkok, Thailand	Miami International	Miami, FL
Bombay International	Bombay, India	John F. Kennedy International	New York, NY
Ezeiza	Buenos Aires, Argentina	Charles DeGaulle	Paris, France
Maiguetia-Simon Bolivar	Caracas, Venezuela	Galeao	Rio de Janeiro, Brazil
O'Hare International	Chicago, IL	Fiumicino	Rome, Italy
Koeln-Bohn	Cologne, Germany	San Francisco International	San Francisco, CA
Kastrup	Copenhagen, Denmark	Singapore International	Singapore
Dallas/Ft. Worth	Dallas/Ft. Worth, TX	Kingsford Smith International	Sydney, Australia
Frankfurt	Frankfurt, Germany	Mehrabad International	Tehran, Iran
Hong Kong International	Hong Kong	Ben Gurion International	Tel Aviv, Israel
Honolulu	Honolulu, HI	Maribel	Montreal, Canada
Jan Smuts	Johannesburg, S. Africa	Tokyo International	Tokyo, Japan
Heathrow	London, England		

Figure 3. Parallel runway separations.

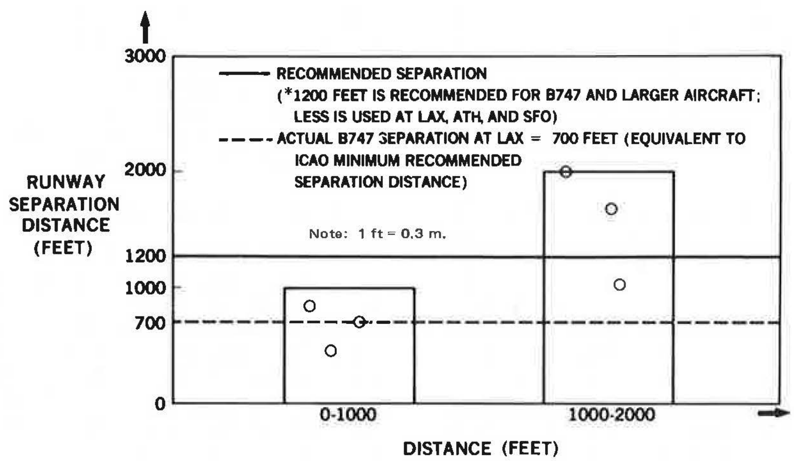


Figure 4. Parallel taxiway separations.

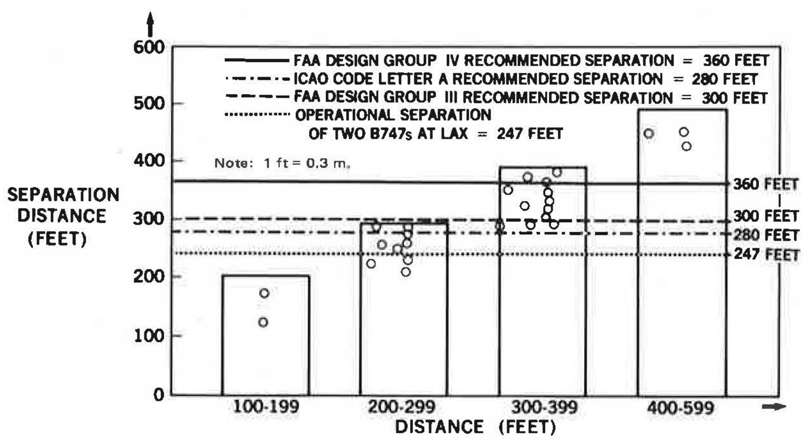
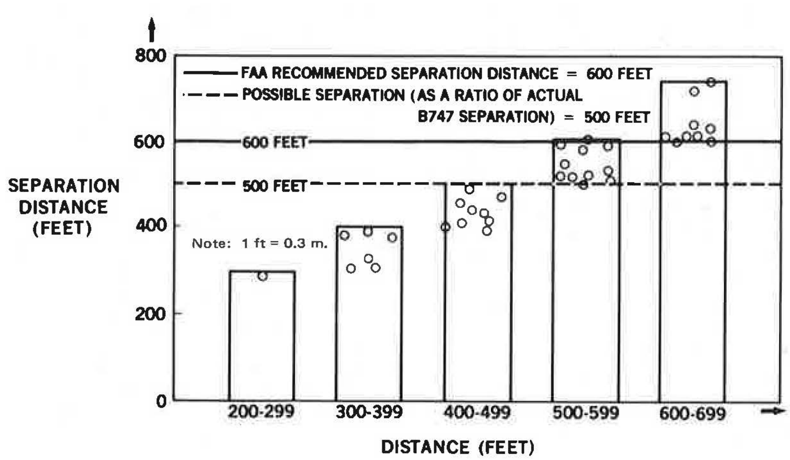


Figure 5. Parallel runway and taxiway separations.



discussed for parallel runway, parallel runway and taxiway, and parallel taxiway situations at the 31 airports. The approach taken, in the absence of a technical rationale for each parallel situation, is developed through (a) analysis of present FAA- and ICAO-recommended minimums listed in Table 1, (b) examination of various deviations from these recommendations, and (c) logical outlining of possible wingspan versus separation relationships. Separation criteria outlined by design group 2 have been examined extensively and tested over the years by various agencies and are considered to be optimum for comparison purposes when analyzing design groups 3 and 4.

Parallel Runways

Aircraft that have a wingspan greater than outlined by design group 3 (B747) and ICAO code letter A are currently defined within FAA design group 4 recommendations. Wingspan and fuselage dimensions categorized within these airport design groups affect parallel runway separation by influencing the position of taxiway hold lines, which define the necessary area for aircraft holding and safety spacing. Larger wingspan and fuselage lengths would, logically, demand greater hold-line distances for (a) additional safety separation distance for runoff clearance, (b) landing deviations, and (c) wake turbulence. Figure 3 depicts existing parallel runway separations and ranks the 31 airports. For the airports that are within the 213 m (700 ft) FAA and ICAO minimum [Los Angeles (LAX), San Francisco (SFO), and Athens (ATH)], no significant compatibility increase can be realized. For the remaining data-base airports (87 percent), parallel runway separations are not viewed as a restrictive factor on wingspan expansion. When compared with the daily use of the 213-m parallel runway separation at Los Angeles for unlimited operation of B747-sized aircraft, the design group 3 recommended separation of 366 m (1200 ft) outlined in Table 1 is considered quite conservative. However, caution is necessary in judging this comparison, because the criteria for determining separation distance are uncertain. Also, many parallel runway situations that consist of two sets of dual runways are individually designated for totally separate functions. Their relationship to each other, therefore, is only that of being parallel and is not considered an influencing factor in this paper (e.g., the dual parallel runways at Chicago O'Hare).

Parallel Taxiways

Present parallel taxiway separations for the 31 airports are shown in Figure 4. FAA- and ICAO-recommended separations are plotted along with operational separations of two B747s at Los Angeles International Airport. As can be seen, approximately 63 percent of the airports fail to meet the 110-m (360-ft) recommendation for design group 4.

Distance requirements for parallel taxiway separation are primarily a function of wingspan, main-gear tread, lateral deviation during movement, and required wingtip clearance. But, when the capability of making a 180-degree change of direction is required from one parallel taxiway onto a second parallel taxiway, wheelbase, steering capability, and taxiway width are also important. The recommended FAA separation distance for design group 3 (B747-sized aircraft) is 91.5 m (300 ft) centerline to centerline (Table 1) and 110 m for design group 4. In attempting to demonstrate the possiblity of lowering these recommended separation minimums, a search was made for airports that currently operate with less separation. One example found is the 75-m (247-ft) parallel separation between taxiway U and ramp taxiway T on the north set of parallel runways at Los Angeles International Airport, where two B747s operate (in passing) simultaneously without limitation as a routine procedure and with no instance of incident or accident. If safe operation of B747s can be performed with a 75-m separation instead of the recommended 91.5 m (a 16.5 m difference), then a wingspan as large as 72.5 m (238 ft) may prove safe and be proportionately compatible within the recommended separations. Initially, the Douglas-projected 70-m (230-ft) wingspan appears compatible for the 91.5-m recommendation, but caution is necessary in recommending any wingspan of a greater dimension, because the proportioning is only valid if (a) wingspan is the only aircraft variable, (b) wingtip clearance is not a function of wingspan, and (c) provision for 180-degree turn capability at design taxi speeds is not required. Therefore, before an accurate appraisal of reduction in parallel taxiway separations can be given, a technical evaluation of various projected aircraft characteristics and operating capabilities, including future design trends, should be undertaken.

Parallel Runway and Taxiway

Design group 4 aircraft have a recommended runway and taxiway separation centerline-to-centerline distance of 183 m (600 ft) for simultaneous operation. This was recently changed from a long-standing 305-m (1000-ft) separation. Design group 3 aircraft have a recommended 122- to 152.2-m (400- to 500-ft) separation, depending on field elevation requirements for simultaneous operation. Comparison of the wingspan dimensions defined by these design groups and the recommended separation minimums imposed shows that the design group 4 separation of 183 m appears compatible for the 70-m wingspan of the projected design limit. However, contact was made with control tower personnel of Kennedy International Airport, who verified their endorsement, without reservation, of operating two B747s on parallel runway 13L and taxiway W, which have a 91.5-m separation. This particular example is depicted in Figure 6. With 91.5 m used daily as an operational procedure, an estimated 152.5-m (500-ft) separation is believed possible for the 70-m wingspan of the projected design limit. The thought is again of a proportionate nature, derived from the difference in recommended criteria and real-world practices, including safety requirements consideration.

The present 183-m separation minimum exceeds the specifications at many of the data-base airports; the possible 152.5-m separation would help to put more airports into a compatible category. Therefore, not all of the airports can become compatible with the theorized reduction of separation minimums but, as with parallel runway and parallel taxiway situations, more airfields are classified as compatible with an acknowledgment of possible nonessential separation. This is shown in Figure 5.

Analysis of a Maximum Wingspan

Critical airside areas have been examined in order to determine the capability of existing airports to serve an aircraft that has dimensions greater than the B747-sized aircraft of design group 3. As Figures 3-5 demonstrate, operations at several of the data-base airports are subjected to stress by the dimensions of the B747, with no foreseeable future capability for unrestricted handling of a larger aircraft. A maximum wingspan of 61 m (200 ft) seems necessary to ensure adequate separation

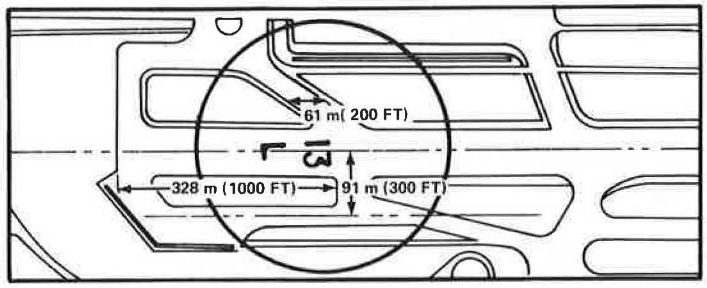


Figure 6. Example of operational separation at Kennedy International Airport.

for simultaneous, unrestricted operations at the domestic and international airports analyzed. This 61-m figure is dictated mainly by the narrow parallel runway separation at Los Angeles, San Francisco and Athens airports, and some additional airports are limited in required parallel runway and taxiway and parallel taxiway separations. By summarizing the presented material, and considering alternative or new airports in lieu of Los Angeles, San Francisco, Athens, Kennedy, and Copenhagen, which have the major limitations, the hypothesized wingspan of 70 m could be considered compatible. This 70-m wingspan is rational because of the small percentage change necessary and the desire for both economical and physical change in the next 20 years at most of the data-base airports. If this speculation is valid, in the past airports have paid a near-term large economic penalty by using too much separation; however, their capability to expand, if required, is enhanced.

Geometric layouts of runways and taxiways at airports to be used in this century and beyond will limit the unrestricted use of a wingspan less than 70 m in a few cases and more than 70 m in most cases. This relationship of maximum aircraft size to airport limits can only be changed by major construction efforts or aircraft design innovations, such as wingtip fold or winglets. To exceed this span recommendation would contradict necessary safety measures.

CONCLUSION

FAA advisory circulars, various handbooks and manuals, and ICAO's construction standards provide recommended separation criteria. Any new aircraft that have greater dimensions than their predecessors create changes in these criteria, which affect compatibility. Although a 70-m (230-ft) wingspan is compatible with many of the existing airports, a number of important international airports cannot accommodate an aircraft wingspan of more than 61 m (200 ft) without sacrificing their capacity to some degree. In this case, the manufacturers must analyze and weigh the impact of these restrictive airports on larger aircraft designs and either design within these restrictions or find alternative airports designed to accept larger aircraft. This is especially true at the larger metropolitan hub airports built prior to the introduction of heavy jet aircraft. These older airports have already reached or exceeded their planned traffic capabilities. Larger aircraft could help to alleviate this traffic problem, but not if it would interfere with the operation of other traffic or cost the airport such an exorbitant amount of money for rebuilding that it would be impractical. A major factor to consider is that some airports are unable to rebuild or change because of lack of space. The availability of alternative airports is limited, and usually they are far removed from the major city hub. If ground transportation for this added distance is not justifiable, then major reconstruction efforts would undoubtedly be needed to make these airports compatible for large operations. This would mean large acquisitions of land and an enormous financial investment.

An aircraft's compatibility with a particular runway and taxiway system is defined as where wingspan or fuselage overall length become critical. Each airport studied may serve aircraft that have a greater than 61-m wingspan, but not without delays, inconveniences, numerous changes in procedures, and encroachment of safety requirements.

It is concluded that a wingspan in excess of 70 m oversteps any capability of change to airside systems and precludes provision of an unrestricted, safe system. Consequently, it is presumed that airport authorities and regulatory agencies will be unwilling to accept a greater wingspan.

A maximum, totally compatible wingspan dictated specifically by runway and taxiway separations at all 31 data-base airports is 61 m. However, a 70-m wingspan is speculated to be compatible with all data-base airports (except Los Angeles, San Francisco, Athens, Kennedy, and Copenhagen) if minor changes are made to some of them.

RECOMMENDATION

A scientific rationale should be developed to technically define necessary separations dictated by aircraft physical and performance characteristics. This would facilitate determination of the airport components for future, large aircraft.

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Flight Simulators

ROY McLANAGHAN

Since thousands of U.S. and allied pilots learned to fly in the "blue box" instrument trainer during World War II, simulation has become increasingly sophisticated. Link has kept pace with advances in aerospace and supplies training systems for each new type of aircraft and also for space vehicles. The company's expertise extends into other areas, including industrial trainers, power plant simulators, naval and maritime training systems, and railroad simulators. The paper covers flight simulation and describes wide-body jet transport simulators that provide the capability and fidelity to train airline crew members in the execution of normal, abnormal, and emergency operating procedures. Military weapon system trainers are discussed, and details given of how they allow duplication of the flight environment of high-performance jet fighters, bombers, and helicopters with realistic reproduction of the radar, electronic countermeasures, and weapon delivery system. Research simulators are represented by the simulator for air-to-air combat, which has a unique large field-of-view visual system, and space simulators are included by reference to the shuttle mission simulator.

More than half a million pilots received part of their initial training during the Second World War in the original Link flight trainer. This device was a pneumatic-mechanical system in which the controls and instruments were similar to aircraft of that period. By present standards, these trainers would be considered primitive, but they nevertheless contributed to the instruction of pilots in the use of instruments and the fundamentals of aircraft control.

When a pilot sits in today's flight simulator, he or she is surrounded by an exact replica of the aircraft he or she is being trained to fly. The instruments and controls are driven by digital computers to respond in exactly the same way as would the actual aircraft. The same computers generate the aerodynamic and mechanical sounds associated with the particular aircraft as well as radio communications and also control hydraulically driven motion platforms to give the pilot the valuable sensory cues that are used to fly the actual aircraft. The scene through the cockpit window is also reproduced, and although this is not as realistic as the other inputs provided to the pilot, it has sufficient fidelity to enable many visual flight maneuvers to be trained.

A major attraction of flight simulators is that they allow all of the time allocated for training to be usefully employed. When an aircraft is used for training, a considerable amount of time may be wasted in waiting for take-off or approach clearance and, of course, in the real-world the training mission will be highly dependent on weather conditions. A number of other factors also make simulators attractive for both civil and military flight training.

EFFECTIVENESS OF FLIGHT SIMULATORS

Simulators may be applied to the following phases of training:

1. Initial training,
2. Advanced training and proficiency training,
3. Crew training tactical operations, and
4. Training in skills that cannot be practiced in the real world.

All of these points are important, but the last one is obviously of overwhelming significance for the military.

The operating advantages of flight simulators are as follows:

1. Safety,
2. Continuous availability,
3. High rate of use, and
4. Low operating costs.

A simulated aircraft may be flown in the most inclement weather conditions with serious equipment malfunction and may, indeed, crash without anybody being hurt. Compare this with the obvious real-world hazard that is present in training a crew to perform an engine-out approach in one of today's jumbo jets. The flight simulator is always available for training, is not dependent on the weather or density of traffic, and is often used 16 h/day, 365 days/year.

A factor that has assumed greater importance with the ever-increasing cost of aviation fuel is the low operating costs of the simulator compared with the cost of aircraft. The ratio of operating costs may be as high as 15:1, depending on the type of aircraft, and it has been estimated that the U.S. airline industry saves 204 million gal of fuel each year by its intensive use of flight simulators. The U.S. Air Force undergraduate pilot training instrument flight simulator program allowed a reduction of 40 h/pilot in the use of T-37 and T-38 aircraft, and in one year, this represents a saving of more than 23 million gal of jet fuel.

Apart from saving fuel, the military also saves ammunition through the use of weapon system trainers. These flight simulators have the capability of training in the operation of the aircraft weapon systems as well as operational flying. Since some of today's advanced weaponry costs in excess of $10 000/round, it is easy to understand why a crew only gets to fire one per year in the actual aircraft. In the simulator, they may practice to their heart's content at almost negligible cost.

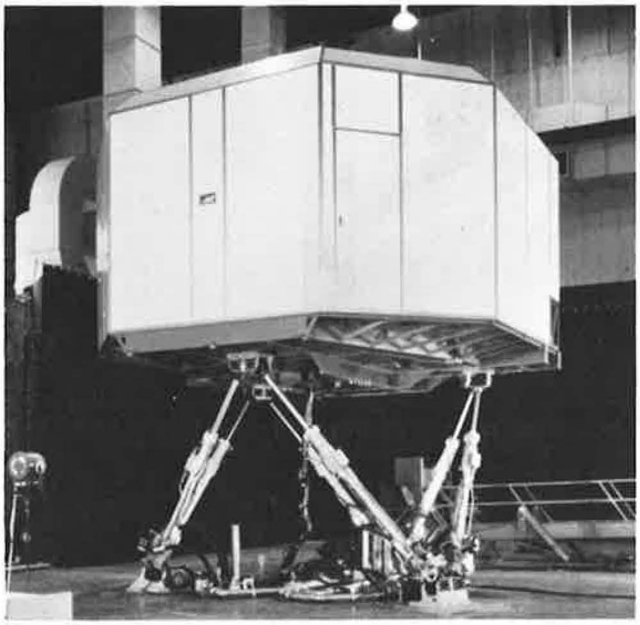
The training advantages of simulators are as follows:

1. Absolute control of the training environment,
2. Standardization of training, and
3. Automated training practice in otherwise impractical tasks.

Control of the training environment means that the instructor is able to select exactly the weather conditions that are appropriate to a particular phase of training. Through the control console, cloud base, cloud top, visibility, temperature gradient, and so on are set up. The instructor determines whether it is day, night, or dusk and the visual scene responds accordingly. The instructor has the same control over the simulated airfield lighting as does the air traffic controller in the real-world situation, and so he or she can select the runway to be lit, lighting intensity, and so on.

Parameters related to the simulated aircraft are also under instructor control, and he or she decides on the weight of the aircraft, fuel load, and center of gravity. As the simulated flight proceeds and fuel is consumed, the weight, inertia, and center of gravity of the aircraft vary accordingly, and the pilot needs to retrim the controls to maintain stability.

Figure 1. Aircraft simulator.



For each aircraft system, whether it be electronic, electrical, or hydraulic, a mathematical model exists in the digital computer. The simulation runs at real-time update rates and every control input produces a corresponding output, perceived by the flight crew through instrumentation and indicators, the feel of the primary flight controls, through the motion system, or as a change in the visual scene through the cockpit window. Because he or she has total control of the simulated aircraft, the instructor may introduce faults and emergency conditions at will.

Consider, for example, the training of a flight crew to cope with the loss of an engine just as the aircraft rotates to assume a positive climb rate and lift off the runway. Apart from the safety aspects of performing this maneuver in the actual aircraft, in order to simulate an engine failure, the instructor must close the throttle for the appropriate engine--not shut down the engine as this would be too dangerous (suppose it was a two-engined aircraft)--and the instructor or another instructor pilot sits in the right-hand seat in case the student pilot cannot cope with the emergency. The realism of the situation is thus reduced to a large extent. Furthermore, the large engines used on jet transports such as the DC-10 develop about 10 000 lb of thrust at flight-idle and about the same amount of drag if they are shut down and windmill. Representation of an asymmetric engine configuration in the actual aircraft is therefore unrealistic and effective training can only be performed in the simulator.

A time-saving aspect of simulators is their ability to transition instantly through time and space, and this means that it is not necessary to waste time on the routine, unproductive segments of a training flight. For both the military and civilian training community, this represents a dramatic reduction in training time. An hour in the simulator is equivalent to more than an hour in the actual aircraft.

With total control of the training environment, standardization of training may be achieved. Every pilot, flight engineer, and weapons systems officer experiences exactly those flight situations that are considered to have the maximum training effectiveness. Standardization of training is further enhanced by taking full advantage of the capability of the digital computer and automating the training process. If it is required that, in a training scenario, an enemy aircraft should manifest itself through the simulated aircraft's sensor systems and in the visual scene at a particular point in the mission, then it is not necessary for the instructor to push buttons or whatever. As a preprogrammed event, the controlling software will introduce the threat aircraft and cause it to behave in a predetermined manner.

The purpose of automated training is twofold. It relieves the instructor of the task of managing the simulator and allows concentration on monitoring and commenting on the trainee's performance. It also improves training effectiveness by fully utilizing the simulator's capability and making every instructor as proficient as the one that designed the automated training scenario. Automatic training features also allow systematic performance evaluation, scoring, and data collection.

In peacetime, the prime task for the military is one of training to ensure combat readiness. Many tasks are impractical to train in the real world. For example, an incursion into a potential enemy's airspace and an attack on a critical target might be difficult to arrange in the real world. The use of similar territory within our own political boundaries does provide invaluable training, but total simulation is the ultimate solution.

Airline Flight Simulators

In the past 10 years, Link has built more than 100 training simulators for the world's major airlines. The list of aircraft simulated includes the early mainstays of the airlines jet fleet (707 and DC-8) through the latest wide-bodies (747, DC-10, L-1011, and A-300). Link is already under contract to deliver simulators for the new Boeing series of aircraft (767 and 757), and it is becoming common practice for an airline to take delivery of the simulator ahead of or concurrent with the delivery of the first of their new fleet.

Figures 1 and 2 show views of simulators mounted on six-axis motion systems. We see that the aircraft cockpit is completely enclosed in its own room to facilitate air conditioning and equipment cooling. Unlike earlier simulators, virtually all electronic equipment is arranged around the exterior of the cockpit and is carried on the motion platform. The new packaging concept leads to higher reliability and ease of maintenance.

Figure 3 shows the interior of a cockpit complete with instructor's station. The most common type of visual system used by the airlines is one that provides a highly realistic representation of the dusk and night environment.

B-52 Weapon System Trainer

The B-52 weapon system trainer, currently in production, is depicted in Figure 4 and includes defensive and offensive weapon stations as well as the flight deck. Three instructor's consoles are used and the complete system is used to simulate an entire real-world mission--from take-off to touchdown--with interactive operation between the cockpit, the offensive weapons, and defensive avionics stations. By using computer image generation techniques, inflight refueling may be practiced. Figure 5 shows the beginning of such an exercise and a KC-135 tanker visible through the forward windshield. Also apparent in this photograph are displays associated with the electro-optical viewing system (EVS) that

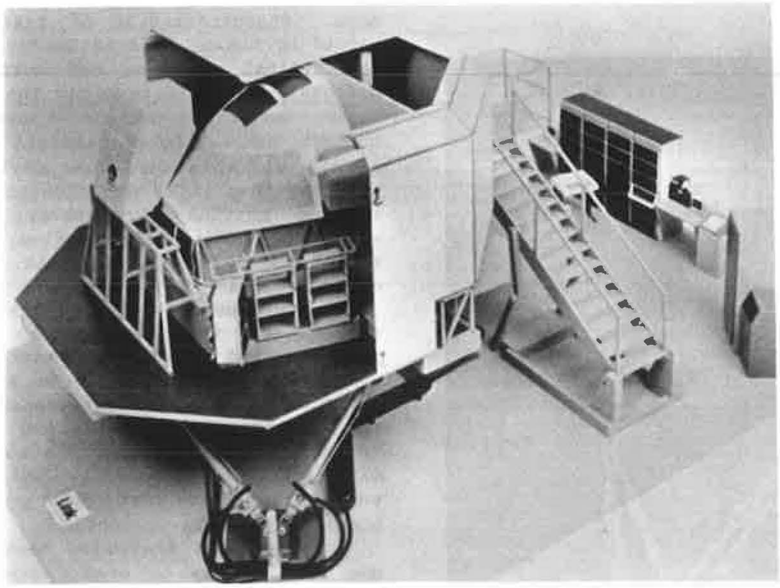


Figure 2. Cutaway view of simulator.

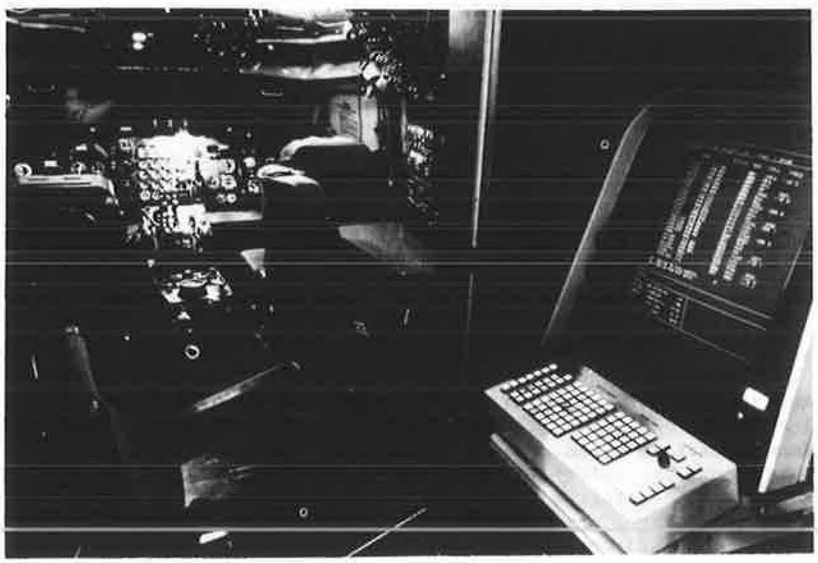


Figure 3. Cockpit interior.

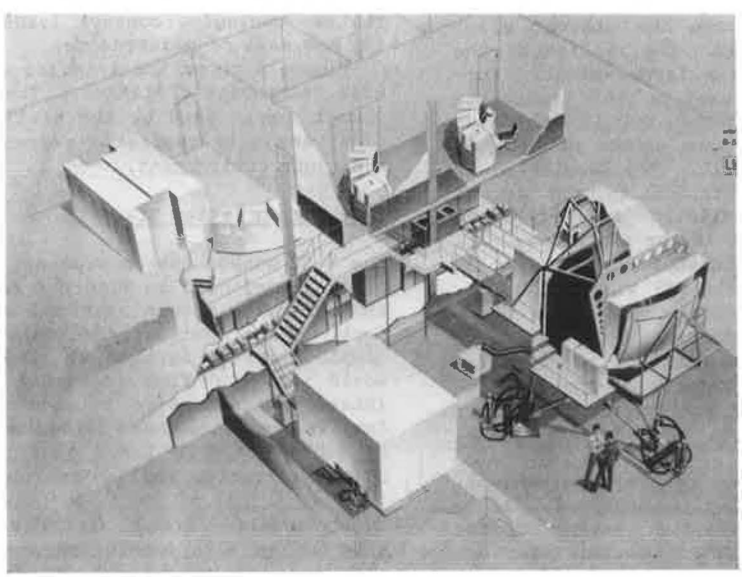


Figure 4. B-52 weapon system trainer.

Figure 5. Interior of B-52 simulator cockpit.

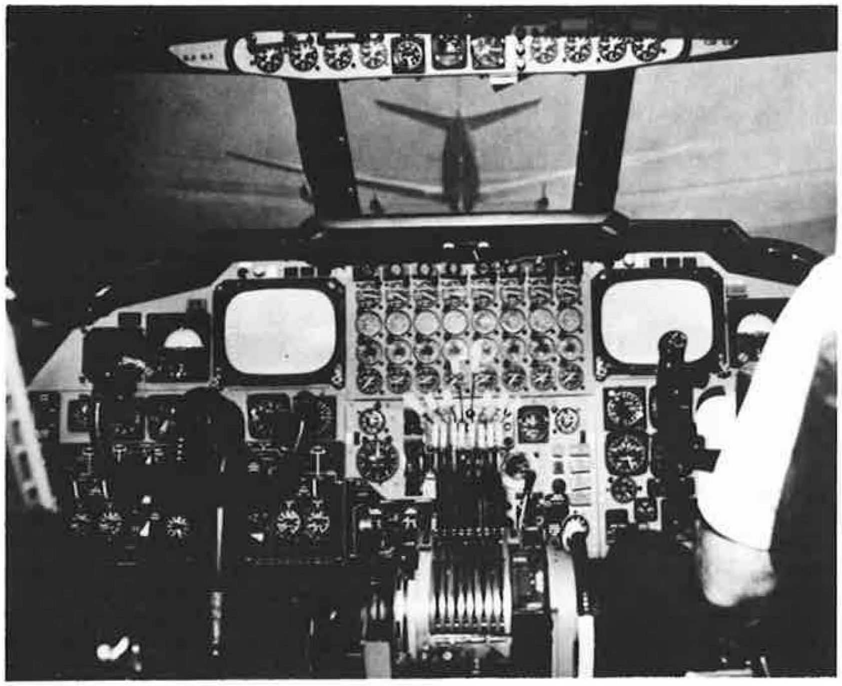
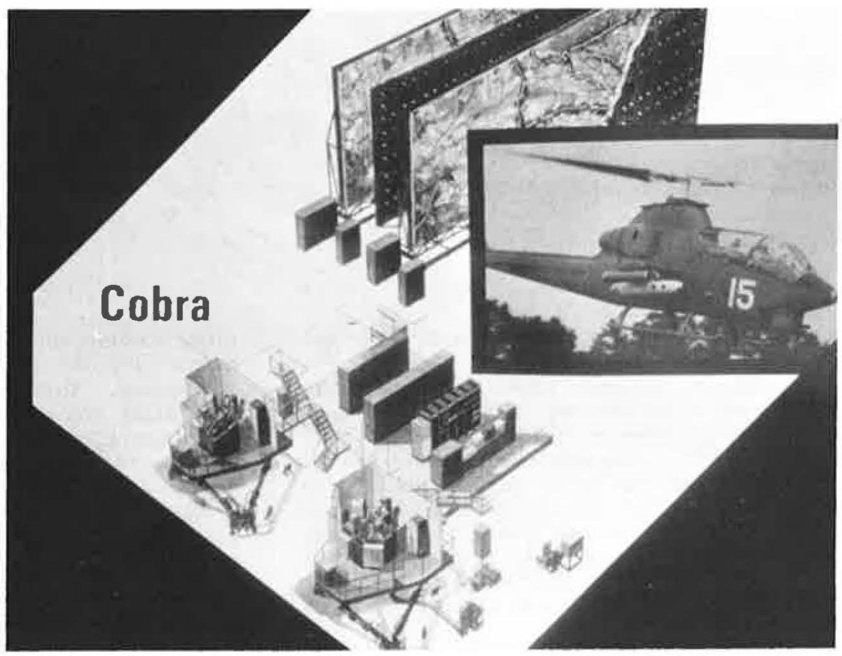


Figure 6. Cobra helicopter weapon trainer.



uses low-light television, forward-looking infrared, and radar information. All of these image systems are fully simulated and correlated with the out-of-the-window scene.

Maximum utilization of the complex is obtained through the ability of the three individual stations to operate in a combined or independent mode. The mode of operation may be changed during an exercise, thus one of the stations may freeze in time and space to review a particular situation while the other two stations continue the exercise without interruption.

Cobra Helicopter Weapon Trainer

The Cobra attack helicopter is a two-place gunship capable of carrying a variety of weapons. Crew members share the operational tasks and the gunner acts as copilot; the pilot is also able to fire weapons.

Figure 6 depicts the arrangement that was chosen for this trainer. The two cockpits are mounted on separate motion platforms--one duplicates the pilot's station; the other, the gunner's. Visual scenes are generated by using model terrain boards and closed-circuit television techniques and, like the B-52 mentioned earlier, the whole system may function in an integrated or independent mode.

Simulator for Air-to-Air Combat

The simulator for air-to-air combat (SAAC) was de-

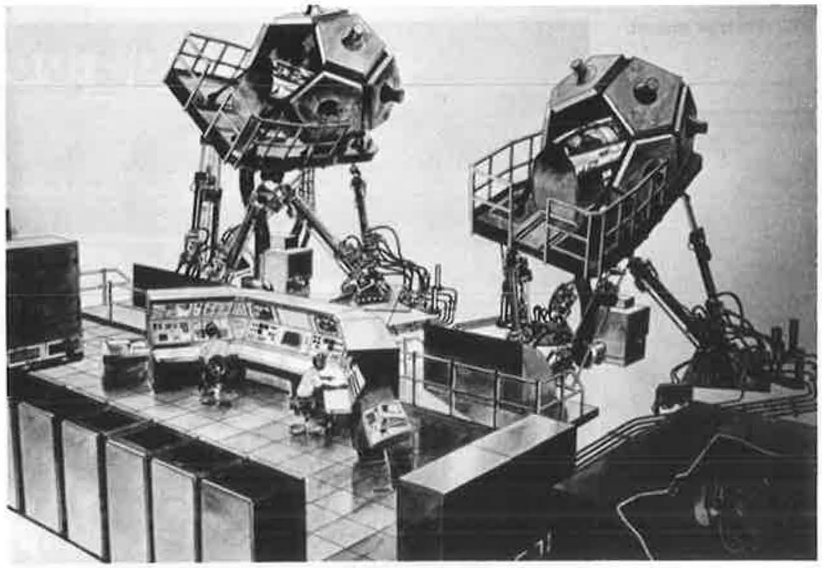


Figure 7. Simulator for air-to-air combat.

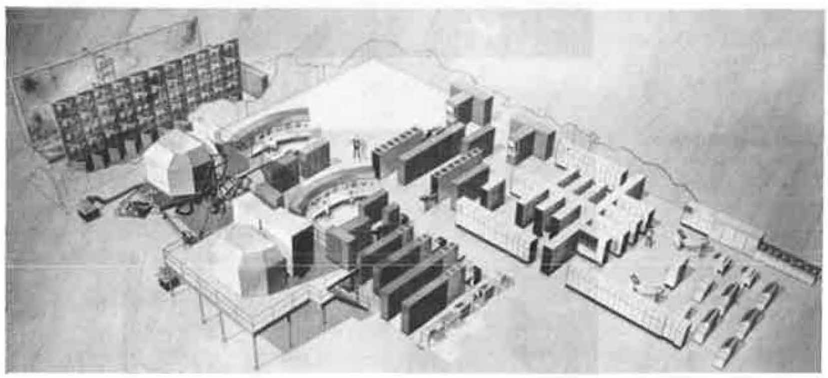


Figure 8. Shuttle mission simulator.

signed and built for the U.S. Air Force by Link and is depicted in Figure 7. SAAC includes two F-4 cockputs mounted on six-axes motion systems. The visual system uses eight pentagonal cathode ray tube (CRT) windows and provides a field of view equal to that of the aircraft. Computer image generation is used to display a terrain image and a view of the second aircraft. A pilot in one cockpit may thus engage in aerial combat with a pilot in the other cockpit and the device is used as a research tool for development of combat techniques and also for evaluation of fighter aircraft and tactical weapons design.

In this simulator the gravity forces experienced by fighter pilots during high-rate maneuvers are simulated by using so-called g-seats and g-suits. Both these devices operate by applying computer-controlled pressures to the surface of the pilot's body. In this manner, the sensations experienced by the pilot during sustained accelerations are reproduced. The g-suit operates in a similar way to the actual g-suit worn by fighter pilots and, in addition, blackout conditions are represented by dimming the cockpit lights and visual scene. In the g-seat the pilot feels pressure caused by air forced into the seat pan, backrest, and thigh panels, in addition to pressure from a controlled lap belt.

Shuttle Mission Simulator

Figure 8 is an overview of the shuttle mission simulator complex currently in operation at the National Aeronautics and Space Administration (NASA) in Houston, Texas. This system is intended to train crews and flight controllers in all of the phases of the space shuttle mission. This includes launch, orbital insertion, orbital operations, and reentry and landing. Both a fixed base and a crew station with a motion system are included in this complex and the visual imagery is available both from a model board system and a computer image generation system. The latter system is capable of supplying imagery through all of the space shuttle flight regimes, including views of the cargo bay with the doors open. Manipulation of payloads into orbit may thus be trained.

SUMMARY

Modern flight simulators have proven to be cost-effective devices and are currently being used to train pilots of commercial and military aircraft as well as astronauts. For the military in particular, many training tasks undertaken in the simulator cannot be performed in the real world.

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Gravitational-Cueing System—An Enhancement of Aircraft Flight Simulation

CHRIS G. HORATTAS

This paper describes a man-machine interface that is used in aircraft trainers to create artificial acceleration cues, which are perceived by the pilot as the cues produced by real environmental effects. This interface, designated as the gravitational cueing (g-cueing) system, translates acceleration components generated in an aerodynamic math model into cues that create sensations experienced in a real aircraft. The g-cueing system is a microprocessor controlled, hydraulically and pneumatically actuated, stand-alone system that can enhance the realism of the simulated flight environment.

Designers of modern aircraft simulators are striving to perfect a man-machine interface capable of producing artificial kinesthetic cues that will be perceived by the pilot as the effects of physical forces. One such interface, which creates cues analogous to gravitational forces, is the gravitational cueing (g-cueing) system.

The g-cueing system replaces the six-degree-of-freedom motion system that has been used in recent years to simulate aircraft motion. The main difference between a six-degree-of-freedom motion system and a g-cueing system is that the former subjects the entire cockpit to motion, but the latter only deflects sections of the pilot's seat and backrest to produce sensations of motion.

FUNCTIONAL DESCRIPTION

In the real environment (with actual aircraft), motion is measured in hundreds of kilometers per hour and distances traveled are measured in thousands of kilometers. In the simulated flight environment, motion is confined to centimeters per second and distances of a few centimeters. This disparity may suggest that it would be impossible to simulate aircraft motion in a simulated flight. However, for a person within the flying aircraft, where there exists no visual frame of reference, the entire airframe appears only to vibrate while suspended in space and no motion is apparent. This exact sensation can be duplicated by subjecting the pilot's seat to only a few centimeters of physical motion. This limited motion is all that is necessary to generate vibration and buffet cues and linear and angular acceleration cues. Acceleration cues can be classified as sustained acceleration cues and onset acceleration cues. Sustained acceleration cues are experienced during a gradual and continuous turn, climb, or dive. Onset acceleration cues are experienced during sudden changes of motion.

The g-cueing system provides the pilot with the sensation of motion, which enhances the simulated cockpit environment during a simulated flight. The motion cues generated by the g-cueing system are functions of stimuli that are generated by pilot manipulation of aircraft cockpit controls or by aircraft systems interactions that affect the simulated aerodynamics. Motion cues are perceived by the pilot through his or her vestibular sensory system. Motion cues can be classified into three categories: (a) directed translation, (b) vibration, and (c) acceleration.

PHYSICAL DESCRIPTION

The g-cueing system consists of several components. Some components are directly involved with the generation of the cues; others are ancillary equipment. Components that are directly involved in the generation of the cues can be divided into three categories: (a) active elements, (b) passive elements, and (c) functional elements.

Active elements are components of the g-seat that have been specially designed or adapted to the g-cueing system to produce certain effects or to create conditions peculiar to the simulated environment. Passive elements of the g-cueing system are components that, by their presence, contribute to the realism of the cockpit environment.

Functional elements are components that perform specific functions in the real aircraft cockpit and are incorporated in the simulator to create a more realistic environment. All functional elements must perform identical functions in both the real aircraft and the simulator.

Some elements of the g-cueing system can have a dual role in the g-cueing system. For example, the lap belt is a passive element when it is used to restrain the pilot in the seat. When the belt is mechanically caused to tense or scrub on the pilot's anatomy, which creates a cue, it assumes an active role.

G-Seat Assembly

The g-seat assembly (see Figure 1) is the most important element in the g-cueing system. It consists of a modified aircraft ejection seat and its accessories. A passive survival kit belt, a functional shoulder harness, and a functional seat height positioning mechanism are accessories of the g-seat assembly that were preserved from the aircraft seat to enhance the simulated environment.

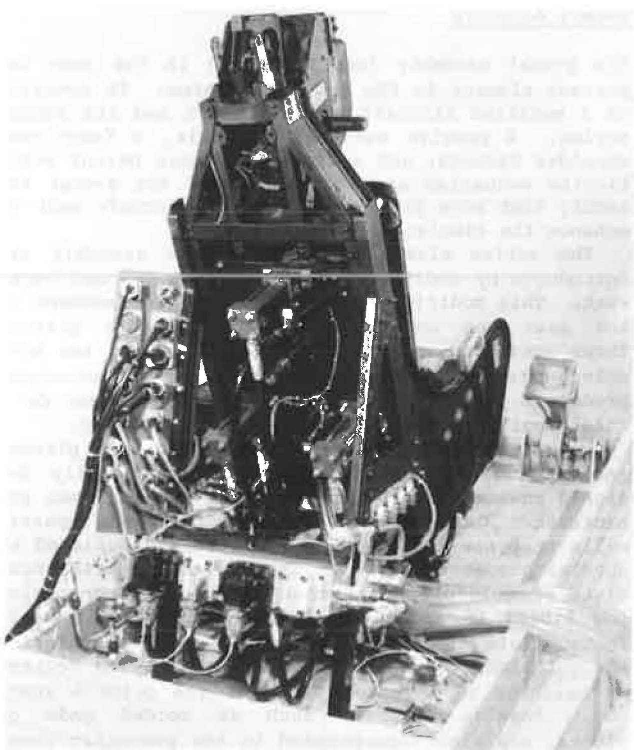
The active elements of the g-seat assembly are introduced by modification of the seat pan and backrest. This modification involves the replacement of the seat pan and backrest with movable plates. Three actuators are attached to each of the two movable plates (see Figures 2 and 3). The actuators produce a heave motion when actuated together or a rotational motion when actuated differentially.

In addition to the seat pan and backrest plates, the modification includes a pair of specially designed pneumatic cushions that line the seat pan and backrest. Each cushion consists of four separate cells that are individually inflated and deflated by special pneumatic valves. The cushion material consists of multiple cells that incorporate constraining fibers to reduce bellowing and ballooning effects. Like the actuators, which cause translation and rotation, the cushions can cause varying degrees of hardness to selected parts of the pilot's anatomy. Passive devices, such as molded pads or blocks, are also incorporated in the pneumatic cushions to provide movement and pressure cues to the pilot's buttocks and thighs (see Figure 4).

The seat pan actuators produce a three-degree-of-freedom motion (i.e., heave, roll, and pitch). This motion can be represented by the combined excursion of the hydraulic actuators (±2.54 cm) and the variable thickness of the seat cushion (±1.28 cm). In the quiescent state, the seat is ±3.84 cm from the zero position. When activated simulta-

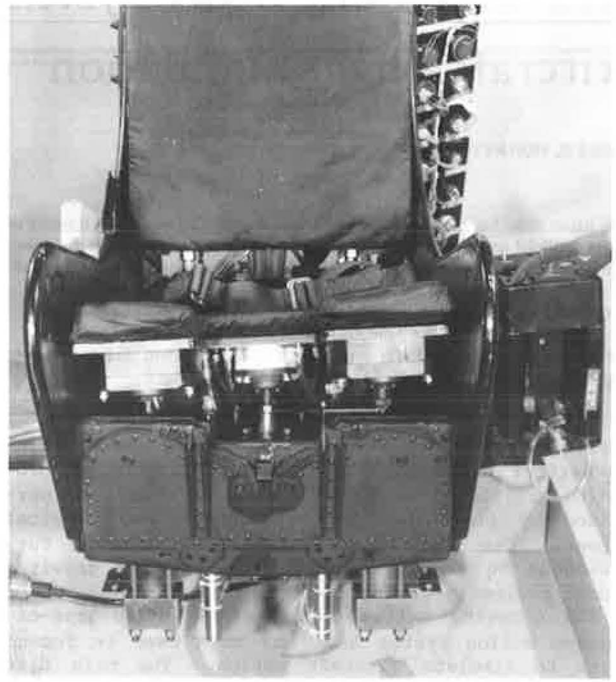
Figure 1. G-seat assembly, front view

Figure 2. G-seat assembly, rear view.



neously and equally, the three hydraulic actuators cause a heave motion. When one actuator is activated in the positive direction and the opposite actuator is activated in the negative direction, a rolling motion is produced. When the rear actuators

Figure 3. G-cueing seat, front view.



are activated in the opposite direction from the front actuator, a pitch motion is produced.

The backrest active elements produce an additional three-degree-of-freedom motion. When all three actuators are activated simultaneously and equally, a longitudinal motion (foreward to back) is produced. This motion is also confined to the ±2.54 cm traveled by the actuators. When the backrest hydraulic actuators are activated differentially and in opposite directions, a yaw or pitch rotational motion is produced.

The backrest cushion operates the same as the seat pan cushion. It provides ±1.28 cm of motion to the backrest due to the variable thickness of the cushion. Linear transducers are mounted on each of the six hydraulic actuators (three seat pan and three backrest), and pressure transducers are mounted in each of the eight cells (four seat pan and four backrest) of the two pneumatic cushions. The transducers provide a closed-loop monitoring system for the g-cueing microcontroller.

Active Lap Belt

The lap belt is a functional component of the real aircraft seat. The belt is incorporated in the simulated cockpit as a passive element of the g-cueing system. In the g-cueing system, under certain conditions, the lap belt also behaves as an active element and produces important motion cues. In the g-cueing system, both ends of the lap belt are anchored to hydraulic actuators. When both actuators are activated equally, a force is applied to the pilot's abdomen, which produces a sensation that is similar to the one experienced in a negative g-acceleration maneuver (aircraft dropping). Conversely, in a positive g-acceleration condition, the belt is loosened and few, if any, cues are generated. When driven differentially, the belt provides the scrubbing sensation that is experienced during lateral and yaw maneuvers.

Figure 4. G-cueing seat pan cushion.

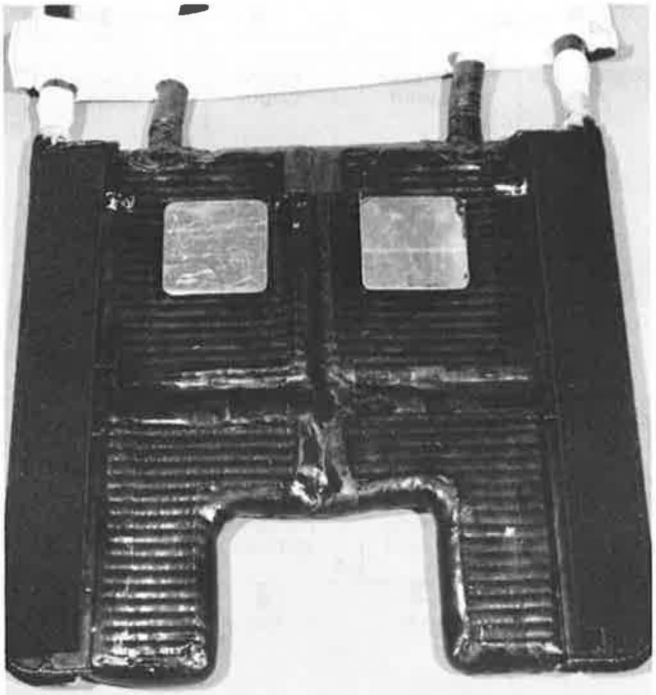


Figure 5. Helmet loader.

Helmet Loader

The helmet worn by the pilot in the real aircraft can be used as an active element in the g-cueing system. Two flexible wire cables are attached to each side of the helmet and anchored at the opposite ends to two motor-driven reels (see Figure 5). Commands from the microcontroller drive the two motors, which reel in part of the cable and cause a force toward the pilot's shoulders. This effect is similar to the weight of the helmet increasing in direct proportion to the gravitational forces.

G-Suit

The g-suit, which is a functional component of the real aircraft, is used to prevent a rush of blood from the brain that could cause blackouts or tunnel vision during high acceleration conditions. The g-suit incorporated in the g-cueing system is an active element. Even though blackouts or other ill effects cannot be generated by the g-cueing system, the g-suit provides the necessary cues that are normally associated with high acceleration conditions. The g-suit is connected to pneumatic and vacuum supplies. In response to the proper command from the microcontroller, the suit inflates or deflates to simulate the discomfort experienced under real flight conditions. The vacuum supply is used to enhance the response of the suit during deflation.

G-Cueing Microcontroller

The g-cueing microcontroller is a specially designed processor and signal conversion unit (see Figure 6) that comprises a pair of state-of-the-art microprocessors and the associated solid-state memory. One of the two microprocessors is a fixed instruction, 16-bit microprocessor designed around a 9900 integrated circuit. This microprocessor provides executive control functions for the entire g-cueing system and is designated as the controller microprocessor unit (MPU). The second microprocessor in the g-cueing microcontroller is a bipolar, bit-slice, microprogrammable device that provides the extremely high computation speeds required for a real-time computation application. This microprocessor is used for arithmetic processing and is designated as the arithmetic MPU. The two microprocessors intercommunicate via shared memory.

Conversion Hardware

The conversion hardware consists of special digital-to-analog conversion (DAC) and analog-to-digital conversion (ADC) cards. The DAC cards are used to translate digital commands to analog signals applied to the servo amplifiers, which drive the hydraulic and pneumatic actuators. The ADC cards provide actuator position feedback to the controller MPU. The cards are bipolar, ±10 volt, full-scale, and provide a 12-bit resolution.

OPERATIONAL DESCRIPTION

G-Seat Dynamics

The g-seat assembly is electronically controlled and hydraulically and pneumatically powered. The electronic control is provided by a microprocessor controller. The microcontroller receives stimuli from a mathematical model of simulated aircraft aerodynamics. From these stimuli, the microcontroller computes the necessary commands that enable the seat actuators to produce the required cues.

System Response

In general, the hydraulic actuators generate onset acceleration cues, and the pneumatic cushions generate sustained acceleration cues. Onset cues are experienced during sudden changes in acceleration (amplitude or direction), and only a hydraulic actuator can provide the required response.

The pneumatic cushions provide the cues in a sustained acceleration maneuver. Sustained accelera-

Figure 6. Microcontroller block diagram.

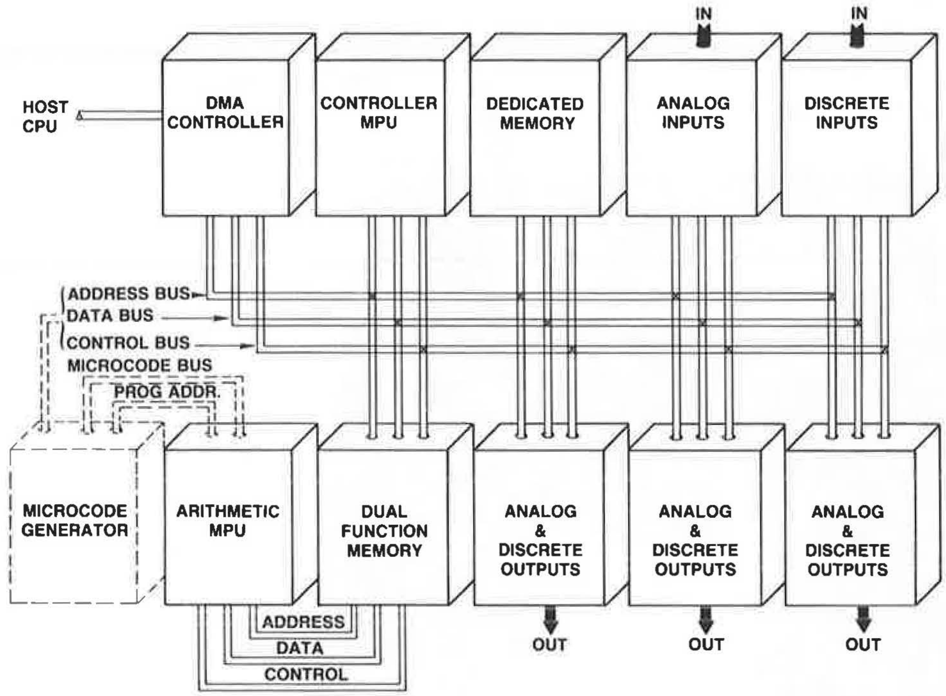
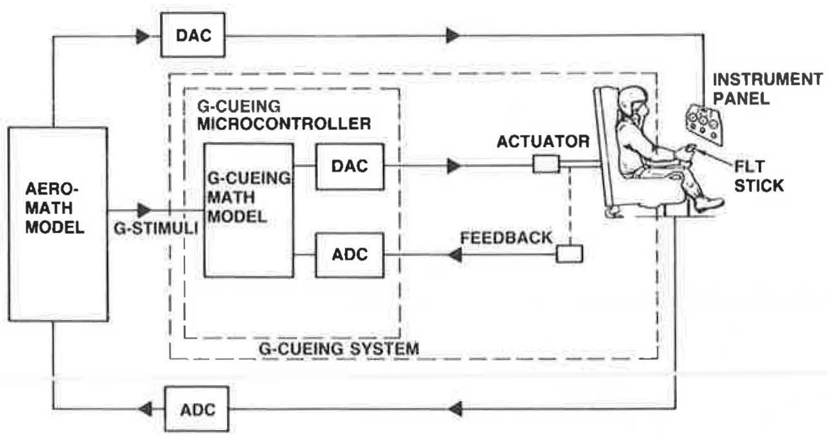


Figure 7. G-cueing system block diagram.



tion cues are experienced when the aircraft is in a gradual and continuous turn, climb, or dive. The cues experienced during such maneuvers are primarily firmness of a section of the seat and a pull on the lap belt. The pneumatic system consists of a pneumatic power supply and four valves per cushion. A special valve and a vacuum supply are used to enhance the response of the g-suit. Primary cues in the g-seat are caused by the hydraulic actuators as onset acceleration cues. These cues are the result of complex coordinated maneuvers of the aircraft, which are translated by the mathematical models into commands to the actuators. A set of secondary cues can be produced by selectively varying the hardness of the seat pan and backrest cushions. Secondary cues are used to simulate sustained acceleration.

The active elements of the g-seat provide a maximum motion of ±3.84 cm. Of this distance, ±2.54 cm is produced by the hydraulic actuators. The remaining ±1.28 cm is produced by varying the cushion thickness.

In addition to the complex composite cues produced by the aerodynamic equations, vibration and buffet cues can also be introduced through the hydraulic actuators. These vibrations consist of combinations of sine-wave signals modulated by preprogrammed envelopes that are generated by the g-cueing mathematical model.

G-Cueing Control

To produce meaningful commands to the various elements of the g-cueing system, which in turn produce composite cues, a mathematical g-cueing model is employed. The mathematical model is contained in a specially designed processor designated as the g-cueing microcontroller. The g-cueing microcontroller is interfaced with and derives the g-cueing stimuli from the aircraft aerodynamic mathematical model. The stimuli consist of load forces that are proportional to the linear and angular accelerations. The load forces are translated into special commands, which are in turn converted to analog signals. These analog signals provide the driving voltages to the hydraulic and pneumatic actuators to produce the corresponding cues. A simplified diagram of the microcontroller-g-seat relationship is shown in Figure 7.

Mathematical G-Cueing Model

The mathematical g-cueing model resides in the microcontroller. This model consists of 29 program models. The mathematical model translates the acceleration control forces stimuli into meaningful commands to the actuators to provide for the proper cues. The various program modules provide for stimuli scaling, integration, interpolation, initialization, fade in and fade out, curve shaping, seat dynamics, and many other control functions.

Simulated Motions

The various actuators produce multiple motion cues simultaneously, as demanded by the flight equations of motion. Listed below are some of the various maneuvers and analogous cues that can be produced by the g-cueing system:

1. Buffet,
2. Stalls,
3. Dives,
4. Climbs,
5. Banks,
6. Spins,
7. Rolls,
8. Vibrations,
9. The sensation of release of stores (e.g., bombs and rockets),
10. Touchdown,
11. Impact,
12. Airbrake application,
13. Landing gear strut dynamics,
14. Ground taxiing including runway rumble, and
15. Landing gear motion.

POTENTIAL PROBLEMS

Eye-Level Shift

In normal level flight, the pilot's eyes lie in a plane parallel to the horizontal, and he or she views the various instruments and displays by simple head and eye motions. During high acceleration maneuvers, the relative level of the pilot's eyes, with respect to the instruments, remains the same (except for approximately 1.28 cm due to thoracic contraction). In the g-cueing simulated environment, the pilot's body is raised and lowered relative to the instruments. This relative positioning of the g-seat can cause exaggerated shift of eye level, which results in negative training. The hydraulically activated seat pan and the pneumatically inflated seat cushion can be moved in opposite directions to compensate for exaggerated eye-level shift.

Pilot Weight Bias

Since all pilots do not weigh the same, body contact with the seat and the sensation of firmness can vary from pilot to pilot. Provisions for the instructor to enter the pilot's weight into the mathematical model alleviates this problem. The 1-g reference, with regard to seat firmness, area of body contact, and quiescent level, is established at system initialization, prior to the start of a mission.

CURRENT STATUS

The g-cueing system described in this paper, less the helmet loader, is contracted for installation in six F-15 aircraft simulators being manufactured for the Royal Saudi Air Force and the U.S. Air Force (USAF). All preliminary studies and evaluation were performed on a laboratory prototype system by using the F-15 aircraft aerodynamic mathematical model as a driver. The g-cueing system has been evaluated by USAF and Navy pilots and many nonmilitary personnel. Most of the pilots had experience on a six-degree-of-freedom motion-platform simulator, although not all pilots had flown the F-15 aircraft. Their comments and critiques aided in the refinement of the mathematical g-cueing model. All pilots agreed that, due to the lack of preestablished guidelines and criteria, their evaluations were highly subjective.

Two pilots that flew the same mission expressed divergent views on specific cues. A majority of the criticism was directed at peripheral hardware (e.g., control stick feel forces, rudder pedals, and throttle quadrant) that, even though not part of the g-cueing system, if improperly simulated could distract and confuse the real cues.

Less-experienced pilots tended to limit their maneuvers to the range of 1 to 4 g's. The more-experienced pilots, and the F-15 pilots in particular, evaluated the performance of the g-cueing system in maneuvers of 4 to 7 g's. Each group wanted the cues to be exaggerated at their particular range. Some pilots felt that the roll maneuver of the seat pan should be reduced, and others indicated that an upper body sway should be added. Most recommendations resulted in changes in the g-cueing mathematical model, which resulted in improved performance characteristics.

CONCLUSION

All of the pilots who have evaluated the g-cueing model have lauded the response of the system and felt that it performed equal to or better than the six-degree-of-freedom motion system. They agreed that the primary cues were adequately simulated and felt that a more-critical evaluation will be possible in a completed simulator environment.

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Laser System for Visual Simulation

ROY McLANAGHAN

The most challenging aspect of flight simulation is representation of the visual scene as it appears through the aircraft windshield. A review is made of the techniques that have been used and a discussion is included of film systems, television cameras and models, and the latest fully digital systems. Helicopter flying at low altitude necessitates the generation of a large amount of visual detail over a very large field of view. Currently in development is a system that uses a scanning laser beam over a detailed model of the terrain over which the simulator is flying and producing a video signal by using a bank of sensitive photodetectors. For display, a direct-writing laser projector is used to cover a field-of-view of 180° x 70° in full color. Prototypes of both the image generator and the projector have been built.

Visual systems were introduced to flight simulators just over 20 years ago and, during that time, a wide variety of techniques has been used. Until the 1960s, flight simulators used analog computation techniques; the development of high-speed, general-purpose digital computers led to the sophisticated devices that we know today. Similarly, the first visual systems were analog and used either a motion picture or a terrain model together with a closed-circuit television system. Today we have progressed to completely digital image generation, thus the gaming area restrictions imposed by the analog systems are eliminated.

Generically, visual systems consist of

1. An information store,
2. A means of scanning and extracting information from that store, and
3. A means of displaying the data.

The table below summarizes three types of visual systems, two analog and one digital.

Visual System	Store	Scanning and Extraction Method	Display
Photographic	Movie film	Movie projector	Projector and screen
Closed-circuit television	Model board	Television camera	Cathode-ray tube
Digital computer	Memory	Computer	Cathode-ray tube

For the photographic technique the data store takes the form of a reel of movie film, the projector is driven to illuminate the appropriate frame according to the simulated aircraft position, and an image is displayed to the pilot on a conventional screen.

VARIABLE ANAMORPHIC MOTION PICTURE SYSTEM

Flight simulators are used for training crews in all aspects of flight and handling procedures. For airlines in particular, the most-critical flight sectors are landing and take-off in all kinds of weather and for different aircraft conditions. During landing and take-off maneuvers, the main cues that the pilot uses are visual and are derived from out-of-the-window scenes. His or her visual sense provides position, direction, attitude, velocity, and rate-of-closure cues. Therefore, the visual simulation system must produce a realistic image of high quality. The choice of a film system to meet these criteria is a natural one--we are all familiar with the high quality of pictures produced at the cinema and with home movie projectors. The variable anamorphic motion picture (VAMP) system uses movie film and functions in the following manner.

Film sequences are made by using a camera mounted in a helicopter that is flying along a nominal flight path for a series of take-offs and landings in a variety of weather conditions. When the film is projected to the pilot of the simulator, the speed and position of the simulated aircraft controls and determines the passage of the film through the projector by varying the projector running speed and selecting the correct frame for display. The pilot will not, of course, fly exactly the nominal flight path employed in making sure the movie and servo-driven distortion optics are used to accommodate a range of flight paths and attitudes around the nominal.

Although film-based systems have the inherent potential for providing images of high realism, the requirement of providing a maneuvering envelope around the nominal flight path led to their demise. A complex anamorphic lens system is required to correct for the flight path deviation and this leads to a reduction in the brightness and resolution of the displayed image. Although correction of eye point position and attitude is satisfactory, the image is distorted such that vertical objects depart from the true vertical and provide negative training cues.

CLOSED-CIRCUIT TELEVISION SYSTEMS

The second type of visual system listed in the preceding table uses a terrain model board as the data store. Models may be as large as 60 x 24 ft and scale factors of 100:1 to 20 000:1 have been employed. Figure 1 shows a typical system. A television camera views the model board through an optical probe and is mounted on a gantry system that allows the entrance pupil of the probe to be positioned at the scaled pilot's eye height above the model board. The gantry system provides translational motion in three axes in response to control signals from the flight simulator. The optical probe includes servo-optics that provide the three rotational degrees of freedom. Thus, at any particular instant in time, the simulated pilot's eye is driven to the correct scaled position and attitude by the flight simulator.

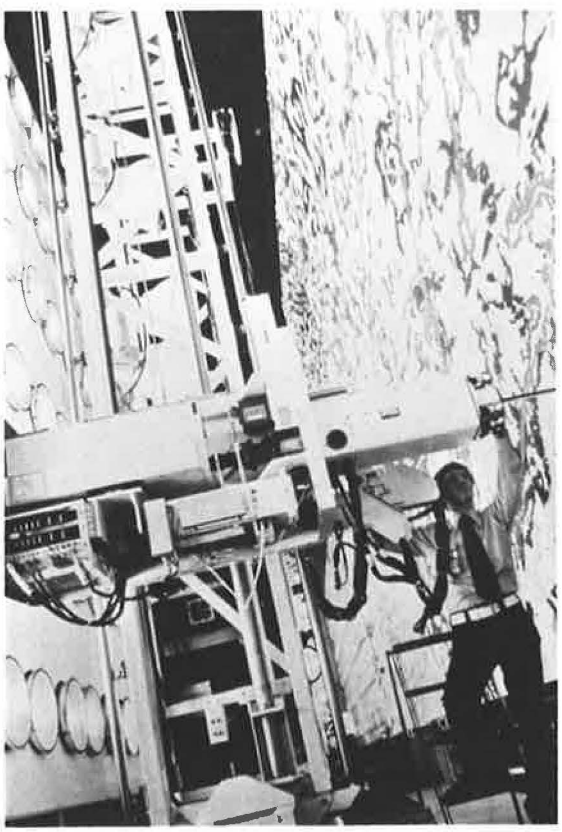
The model board is illuminated by the bank of high-intensity lamps seen to the left of Figure 1. An enormous amount of detail is included in the model board and, when a high resolution television camera (1000 lines) and display monitor are used, an image of high realism is obtained. The major disadvantages of the camera and model system are the high running costs associated with the lamp bank that consumes close to 200 kW of electrical power and the limited gaming area provided by a model board of practical scale and size. The scale factor determines not only the gaming area for a given model size but also the closeness of approach of the optical probe to the model board at minimum flight altitude. For a scale factor of 1000:1, a 60- x 24-ft model board provides a gaming area of 52 miles² and, if the minimum required eye height is 10 ft, then the probe must be able to operate as close to the model board as 1.18 in.

COMPUTER GENERATION OF IMAGES

Computer generation of images (CGI) is the term used to describe visual simulation systems in which the environment in which the simulated aircraft is flying is described by numbers or bit patterns and held in a digital memory. This numerical description of some part of the real or imaginary world is usually called a data base and is operated on by the digital computing complex to generate appropriate video signals to drive a display device that is being viewed by the pilot.

Figure 2 illustrates the elements of a CGI visual system. The environment model is stored on a rapid access disc file and may represent a gaming area, say of 100 x 100 miles, or the whole world. Bulk storage devices are relatively inexpensive and the gaming area is really only limited by the cost of preparing the data base, which in turn is highly dependent on the amount of detail in the data base. The general-purpose computer reads into its high-speed memory that part of the data base that is within visual range of the simulated aircraft and, together with the special-purpose hardware, performs the perspective transformations necessary to generate the correct view of the objects in the data base. Occlusion of one object by another must be taken into account and, finally, information regarding color, intensity, and effects of atmospheric fading are added.

Figure 1. Camera model system.



The major attraction of CGI in visual simulation is its flexibility. Apart from the multitude of environmental models that may be stored and displayed, a single system may also store and generate moving vehicles on the land or in the air. This is obviously important for military applications. Figures 3 and 4 are examples of the scenes generated by a Link digital image generator (DIG) system (the actual system is in full color).

COMPARISON OF THREE TYPES OF VISUAL SYSTEMS

The logical sequence that we follow in selecting a visual system for a training simulator is as follows:

1. Define the mission to be trained,
2. Determine the skills required to perform the mission, and
3. Establish the visual information required to train these skills.

When we simulate the behavior of a cockpit instrument, we do it by effectively duplicating the visual appearance and performance of that instrument. In fact, the instrument may well be an actual aircraft instrument and the simulation task reduces to one of merely providing the correct drive signals to that instrument. The human visual system has a processing capability well beyond the performance limits of currently available image generators and displays. Even the film system that we described earlier cannot match the human eye as far as field of view and resolution are concerned. When we follow the sequence for selecting a visual system as listed above, we usually have to make compromises because a single type of visual system can rarely supply all of the visual cues required for a complete training program.

Figure 2. Elements of computer image generator.

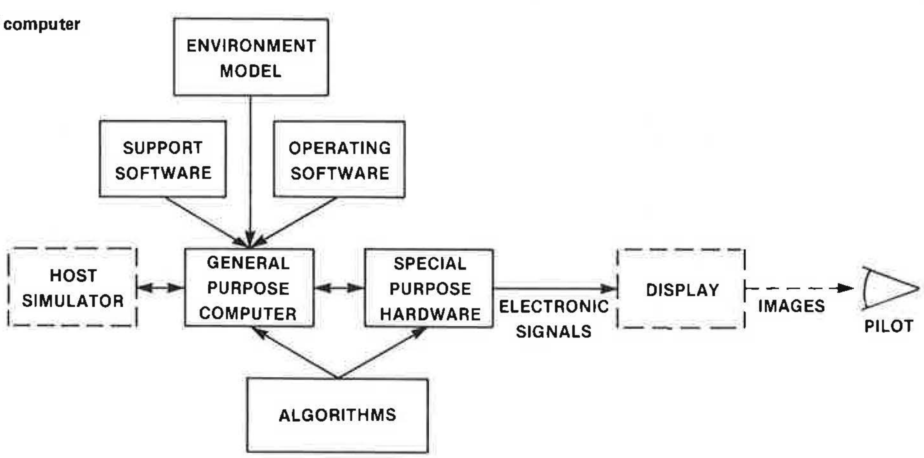


Figure 3. Example of DIG image.

Figure 4. Example of DIG military application.

The table below presents a comparison of the three types of visual system we have discussed.

Visual System	Advantage	Disadvantage
VAMP	High resolution, real-world scenes	Limited maneuverability
Camera and model	High detail, real-world scenes	Limited gaming area
CGI	Flexibility	Computing power limits detail

At one end of the scale we have the film system that provides real-world scenes at relatively high resolution but requires that the simulator follows closely the path of the vehicle that provided the platform for making the original movie. For a locomotive simulator, this might be considered to be the ideal visual system, but it would be totally inappropriate for an air-to-air combat simulator. At the other end of the scale is the CGI system that enjoys the freedom of maneuverability of the real world but cannot reproduce real-world detailed scenes. If the total computing power of the CGI system may be devoted to a single inanimate object, however, it does an excellent job, as we saw in Figure 4, which depicts an aircraft. For air-to-air combat, then, CGI would probably be the most-appropriate choice.

In between these two extremes of the film and the CGI, we have the closed-circuit television (CCTV) model board system. It generates high-detail, real-world scenes and faithfully reproduces the features included in the model. The model is relatively inexpensive to produce and is mainly an artistic rather than a scientific data base, like the movie film. The system does not have maneuverability limitations like the film system but approaches that of the CGI. The gaming area is severely limited by the size of the model board and scale factor, however. A 60-ft long model board at 1000:1 scale factor represents 11 miles of terrain. A high-speed fighter or attack aircraft would cover this territory in a little more than a minute during low-level flight, so this system is not suitable for training pilots in terrain following and avoidance flying.

For a relatively low-speed aircraft like a military helicopter, where the pilot stays close to the ground to avoid detection by the enemy, the CCTV system is considered to be a good compromise. The pilot requires high scene detail to perform a visual navigation task and to judge rates of closure and distances; the system can provide this detail with sufficient fidelity. Missions can be planned that keep the simulated helicopter within the confines of the model board and have an elapsed time similar to the real-world scenario.

A number of these systems are currently being operated by the U.S. Army to provide training for the Chinook, Blackhawk, and Cobra helicopters. Due to the continually increasing cost of energy, Link has sought ways of reducing the running costs of these systems and, to this end, we have developed a laser image generation visual.

LASER IMAGE GENERATOR

The conventional camera and model system pictured in Figure 1 includes a television camera, an optical probe, and a high-intensity lighting bank. The system currently in use is the result of 20 years of development effort and employs the most-sophisticated television technology. Link developed a 1000-line, full-color television to achieve a substantially increased resolution capability over commercially available devices. The weaknesses of the existing systems are as follows:

1. Although the static resolution is excellent, the camera tubes exhibit a condition called dynamic lag. Briefly, this is concerned with the image-retention properties of the tube from one frame to the next and is evident to the viewer as a degradation of resolution or defocussing of the displayed picture under dynamic conditions.
2. High-resolution television calls for four camera tubes, one for each primary color and a fourth known as a luminance channel. This use of four tubes increases the registration and linearity problems and complicates the optical system.
3. The conventional camera and model system is operated in a highly unfavorable optical situation. We require a large field angle to give a good field of view and we require high f-number to achieve a good depth of focus. The optical probe must be small, however, to be able to function with a sensible model scale factor, and we find ourselves working with insufficient light input. Attempts to relieve the depth-of-field problem result in larger optical acceptance angles without any corresponding increase in field of view.
4. The lighting bank required to illuminate the model board consumes around 200 kW of electrical power. This high illumination level is required to compensate for light loss due to spectral separation filters and light loss due to scattering inefficiencies of the model itself.

We need to eliminate the television camera from the system if we are to overcome these difficulties and still retain the desirable qualities of the system.

The use of a scanning laser beam achieves this by reversing the conventional image-generation process. In Figure 5, in the conventional arrangement, we illuminate the object to be televised with an even, constant level of illumination and image the object through a lens system on to the television camera tubes. By scanning the pick-up tubes with an electron beam we are able to generate a raster format video signal that will drive a display that may be either a cathode-ray-tube (CRT) monitor or a television projector.

The laser concept is shown on the right of Figure 5. Instead of flooding the complete object with light, we illuminate only that part of the object to be televised. A laser beam is passed through an optical probe similar to that used in the conventional system and is caused to scan the appropriate part of the object to produce a raster pattern that may be likened to that described by the electron beam on the camera pick-up tube. The reflected laser light is collected by an array of sensitive photocells and a video signal is generated by synchronizing the processing of the electronic output of the photocells with the passage of the laser beam across the object. So, instead of illuminating the whole model board and producing an image of only one small portion of it at any instant in time, the laser image generator illuminates only that portion of the model that is within the visual field of view, on a television line-by-line basis.

An artist's conception of a completed system is shown in Figure 6. The terrain model board and gantry are identical to those in a conventional system, but instead of a television camera being carried and positioned over the model board, an optical laser scanning complex is located in the same position. In place of the lighting bank that was used to illuminate the model, we have an array of photomultiplier tubes arranged in groups of three. These triads receive the reflected light from the model board and the three photomultipliers in a triad each have a color filter placed in front of it to make it responsive to either red, green, or blue. We can thus compose a color video signal by summing together all of the triad outputs by color channel.

On the left of the artist's concept is shown the laser package that generates the pseudo-white light beam that is scanned over the model. The model and the gantry are contained in a light-tight room to avoid spurious light from falling on the photomultipliers.

An Argon laser provides the blue and green components and a Krypton laser provides red. A dye laser pumped by a portion of the green line generates a fourth color line in the orange sector of the spectrum. These four color lines are mixed together after being expanded to produce a 2-in diameter beam, the color spectrum of which has been selected

Figure 5. Comparison of television and laser systems.

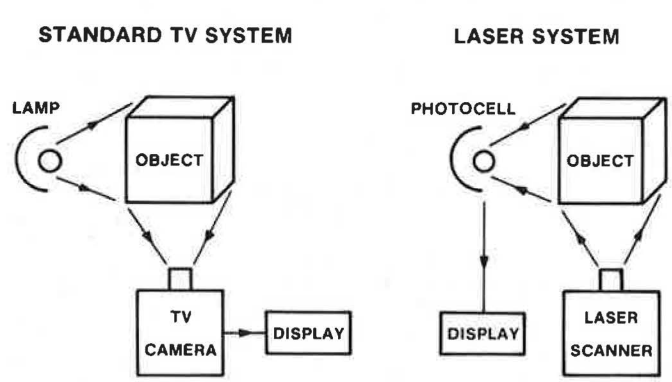


Figure 6. Artist's conception of laser image generator.

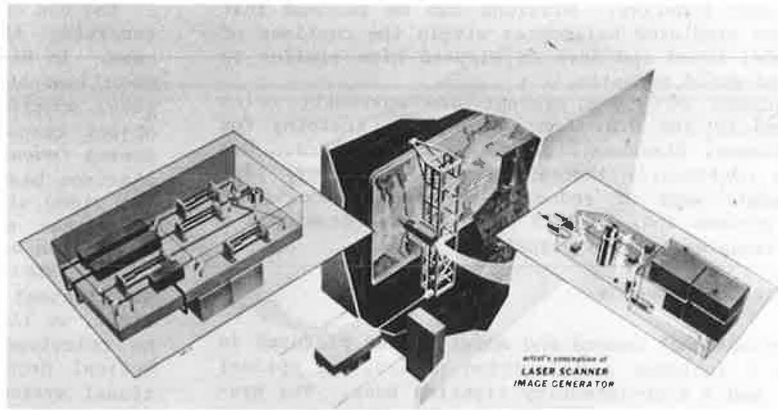
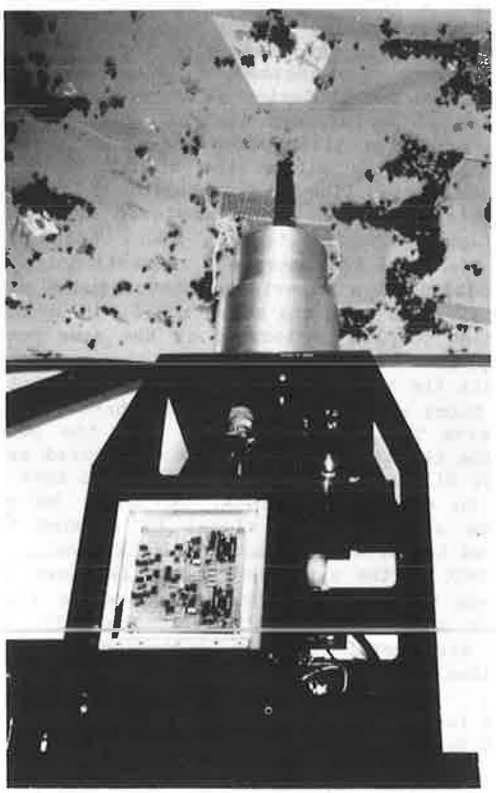


Figure 7. Scanning head.



to match the pigments in the paints on the model board. This beam is collected by a mirror located at the foot of the gantry and is directed toward the scanning head assembly, along the vertical axis of the gantry.

The laser beam was expanded to a 2-in diameter bundle for two reasons:

1. With the energy somewhat dispersed, it provides a measure of safety and
2. It is easier to track the larger diameter beam as the gantry travels along the model board.

When the beam arrives at the scanning head, it is reduced down to 0.04-in diameter and any beam-pointing errors are corrected by an optical servo system. The horizontal scanner that produces the horizontal scan lines of the television raster is a rotating mirror plygon that has 24 facets. It is fabricated from a solid block of beryllium and rotates at 76 000 revolutions per minute. The laser beam is deflected by each of these mirror facets to produce 30 000 raster lines per second. That is 1000 lines per frame at 30 frames/s. From the horizontal scanner, the laser travels to the vertical scanner that is a simpler galvonometer, stepping at 1000 times per frame to provide the vertically scanned field of view. A 2:1 interface is employed and, in the prototype system, a field of view of 48 degrees horizontal by 36 degrees vertical is covered. The laser beam passes from the horizontal scanner through the optical probe that applies the simulated aircraft heading, pitch, and roll motions to the scanning raster format.

Figure 7 shows the scanning head illuminating the model board. The photograph in Figure 7 was made with the model board room lit, but under normal operating conditions the area of the model outside the scanned raster would be in darkness. For the prototype system, the images are displayed on a high-resolution CRT, and an example is shown in Figure 8.

The prototype system was completed in 1978 and proved the feasibility of the laser image generator concept and current development efforts are being directed toward extending the field of view up to 180° horizontal by 70° vertical.

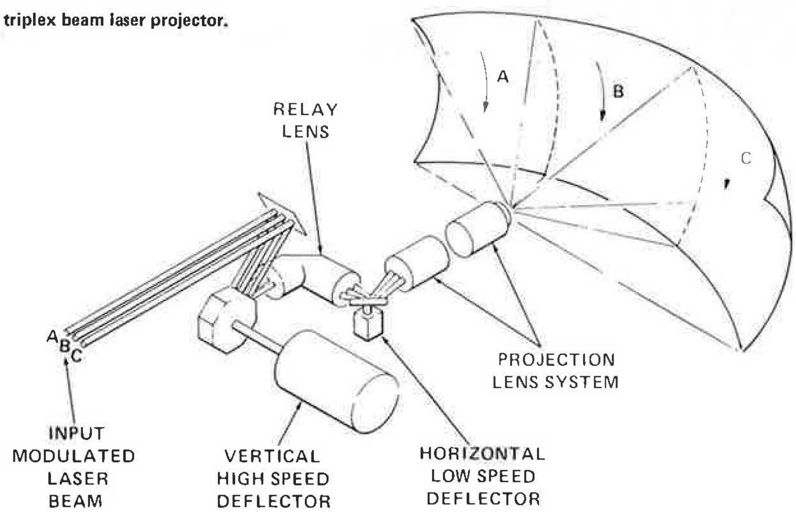
LASER PROJECTOR

The simulator industry normally depends on the television equipment industry to provide monitors and projectors for our visual systems. As we are required to maintain a high-resolution image, there is a limit to the field of view we can generate from a single display device and this is typically 48°x36° with a 1000 raster line system. If we want to cover a larger field of view, then we have to use a matrix of CRTs or projectors mounted around the cockpit. This poses certain problems apart from those involving mechanical considerations. Juxtaposition of a number of CRTs to provide a continuous field of view is difficult in the horizontal direction and even more so in the vertical, and a similar problem exists for television projectors. It is also a maintenance problem to achieve constant color balance and brightness over a matrix of devices.

The direct writing laser projector offers a solution to these problems as it has the potential of covering a large field of view from a single device. A wide-angle laser projector is shown in Figure 9. This concept is a multichannel device for the following reason. If we are to maintain resolution and frame rate over the larger field of view, then the bandwidth of the system must increase. For the laser image generator this is no problem, but if

Figure 8. Laser image.

Figure 9. Principle of triplex beam laser projector.



the input video is derived from a CGI system, then for a given amount of image detail these systems are bandwidth limited. For practical purposes the 48°x36° field of view represents the upper limit for bandwidth and, if our computing power increases, we prefer to use it to include more detail in the image. Large fields of view for a CGI are therefore derived from a multiplicity of CGI channels, each channel being dedicated to a particular segment of the total field. Our laser projector, therefore, uses a number of scanning laser beams, each scanning a segment of the total field and driven by a CGI channel. If a laser image generator is the input device, then a single laser beam scans the whole field.

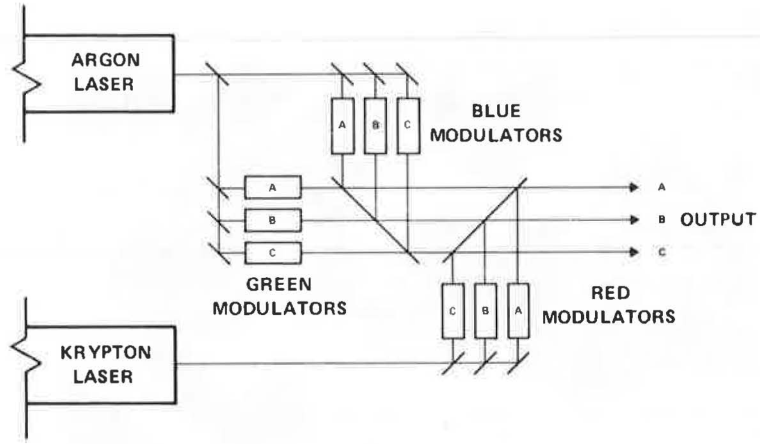
Figure 9 depicts a three-channel system. Three laser beams are generated by the laser package, each beam being modulated in intensity according to the video signal on the three video channels. These beams pass through a horizontal and vertical scanning system very similar to that described in the laser image generator. The probe on the latter is replaced by a projection lens and each composite laser beam scans a sector of a spherical screen.

In order to create a laser beam whose color content is controlled by a video signal, we again start with an Argon and a Krypton laser, as shown in Figure 10. The Argon laser provides both the blue and the green lines, and the Krypton provides the red. For our three-channel system, each of these lines is split into three separate channels: A, B, and C. Each color channel has in it an acousto-optic modulator that alternates the intensity of the laser beam according to the video signal on that particular color channel. The outputs of the modulators are summed together (red, blue, and green) to create a light beam for each channel that covers the spectrum from blue to red.

These three modulated laser beams travel together to the scanning package in a manner similar to that illustrated in Figure 9. The high-speed line scanner and the low-speed frame scanner are the same devices we used in the laser image generator except that now, with the increased vertical field of view, we are scanning the line in the vertical direction, each horizontal sector being 45°. The three laser beams are separated in the projection lens system to scan the three separate fields of view. To cover 180°, then, we would have four laser channels and we would require eight channels of CGI video to cover the total field of view.

A prototype of a single channel of this system has already been completed.

Figure 10. Laser package.



SUMMARY

Three different types of visual simulation systems have been described. Each excels in a particular training environment; the laser visual system offers a solution to helicopter low-level flight training. A system that provides a large field of view is currently in development.

Publication of this paper sponsored by Committee on Simulation and Measurement of Driving.