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EVALUATION OF ROUTING AND SCHEDULING CONSIDERATIONS FOR POSSIBLE FUTURE COMMERCIAL HYPERSONIC TRANSPORT AIRCRAFT

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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1. INTRODUCTION

NASA is moving forward with the development of the basic technology which will be necessary for the future development of very high speed commercial transport aircraft. Areas of special interest include:

- configurations for favorable lift and drag
- engine development
- minimization of sonic boom pressures
- thermal protection systems
- possible use of liquid hydrogen fuel

Additional considerations which are vitally important to the commercial operational use of the aircraft are the projection of the particular travel markets which would be served and the ability of the airlines to schedule and route the aircraft in a way that would achieve good daily utilization and productivity.

This study is an examination of these latter considerations. Included are:

- identification of the major long-haul city pairs that would most likely demand non-stop service
- selection of flight tracks observing alternative sonic boom restrictions
- estimation of flight times for all city pairs for the various sonic boom constraints
- impact of airport curfews on possible departure and arrival schedules
- projection of passenger traffic volumes on the selected city pairs
- potential daily utilization and aircraft productivity

2. SUMMARY OF FINDINGS

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2.1 HST Flight Tracks

For each of the city pairs identified in the forecast analysis, Speas Associates determined the aircraft flight tracks that could be used. Three different rules relating to sonic boom constraints were used:

(1) no constraint, - aircraft produce no boom or acceptably low boom signatures to allow unrestricted overland operation

(2) strict constraint, - supersonic overland operations prohibited

(3) mixed constraint, - aircraft boom signatures are acceptable during cruise operation but not during acceleration or deceleration phases.

Additional constraints were placed on the aircraft acceleration rates, deceleration rates and turning load factors to represent probable operational capabilities of a commercial HST aircraft. Detailed discussion of all of the tracks selected appear in Section 5 of this report.

Aircraft flight times and block times were computed for all city pairs under each sonic boom rule for vehicle design speeds of Mach 2.0 up to Mach 8.0. A subsonic Mach 0.9 aircraft was used as a reference base.

2.2 Routes and Traffic

Principal markets which would be served by HST aircraft were selected based on criteria including long range, high traffic density and overwater operations. There being no range limitation on the aircraft for the purpose of the study, the list included several which do not currently receive non-stop service.

For the purposes of the analysis, the markets were grouped geographically to produce 22 city pairs which represent the great majority of potential HST traffic. Flows on these city pairs were estimated for 1972 and projected to the year 2000 to provide the basis for the scheduling analysis.

The North Atlantic market represented by the city pair New York-London is projected to continue to be the largest HST market, constituting almost 25% of the forecast traffic. A second North Atlantic market, from north central North America to northwest Europe and represented by the Chicago-London city pair, is in second position in the year 2000 with just under 14% of the traffic.

2.3 Aircraft Productivity

In order to explore the possible application of commercial HST aircraft on world-wide route networks, a scheduling analysis was made to determine the extent to which the overland sonic boom constraints would limit the potential aircraft productivity, and to see whether or not the combined circumstances of widespread airport night curfews and short flight times would be an impediment to efficient aircraft scheduling.

If HST aircraft are confined to a single passenger market area such as the north Atlantic, increasingly faster aircraft are not necessarily increasingly more productive.

In a broader analysis encompassing a world-wide route system it was found that aircraft productivity would tend to increase with increasing speed capability. Postulating that the most appropriate comparative measure of aircraft productivity should be the average number of miles that an aircraft can fly in same amount of elapsed time (including time for ground turnarounds), Speas Associates estimated the relative productivity of aircraft with design Mach numbers up to 8.0. In the absence of overland sonic boom constraints a Mach 8 aircraft could be 2.9 times as productive as a subsonic Mach 0.9 aircraft. With the most strict boom constraints this factor is only 2.0 times. In the case of mixed constraints (allowing supersonic cruising flight over land) the relative productivity was estimated to be 2.3. The variation of productivity with Mach number and type of constraint is shown more fully within the report. The significance of the sonic boom constraints is such that a Mach 8 aircraft which had to abide by strict overwater sonic boom rules would only be as productive as an unrestricted Mach 3 aircraft.

3. AIRCRAFT DATA

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3.1 General

This study considers aircraft whose design Mach numbers could be between 2 and 8. For reference to subsonic aircraft a cruising speed of M0.9 has been used, representing probable evolutionary improvements to subsonic aircraft through the time period while the hypersonic vehicles are undergoing development.

Three distinctly different sonic boom constraints have been used:

(1) no constraint, - aircraft produce no boom (or acceptably low boom signatures) allowing unrestricted overland operation

(2) strict constraint, - supersonic overland operations prohibited

(3) mixed constraint, - aircraft boom signatures are acceptable for overland operations during cruise operation but not during acceleration or deceleration phases

For very high speed aircraft, the distances required for enroute acceleration and deceleration, and the possible turning radii are very large (in the order of hundreds of miles). For the purposes of defining and selecting aircraft flight tracks, NASA specified to Speas Associates the following basic parameters:

(1) the maximum range capability is indefinite

(2) the average longitudinal component of acceleration and deceleration, expressed in g's is $0.02M_d$ where M_d is the vehicle design Mach number. For example, a Mach 6 aircraft acceleration would be 0.12g or about 3.84 ft/sec/sec

(3) for passenger comfort, the maximum normal load factor in sustained turning flight would be 1.125g. This implies a bank angle of about 27°.

For these latter two conditions the acceleration and turning performance characteristics would be:

Design Mach Number	Acceleration Distance* (n. mi.)	Acceleration Time* (min.)	Radius of Turn (n. mi.)
2	240	19.4	40
3	373	21.5	89
4	503	22.6	159
5	633	23.3	248
6	761	23.7	357
7	890	24.1	486
8	1,018	24.3	635

* From 300 knots initial condition

3.2 Computation of Block Times

For the estimation of aircraft block times for each of the city pairs, NASA specified that time and distance allowances be included as in Reference 1 (the "1967 ATA formula"). Specifically these are:

Distance - add 20 miles plus 2% of trip distance

Time - 15 minutes ground time plus six minutes air maneuver time (no distance credit)

The enroute portion of the flight is considered to begin and end at a speed of 500 ft/sec (about 300 knots). This is the speed at the end of the takeoff maneuver or the initiation of the landing maneuver.

In general, the flight path from a point A to a point B for the aircraft which must observe boom restrictions may be divided into three segments R_1, R_2 and R_3 whose sum is the path length (but not necessarily the great circle distance) from A to B.

> R_1 is a boom-restricted segment which begins at A. Typically this is the overland path from the airport to the coastline which must be flown subsonically.
>
> R_2 is an unrestricted segment where boom-producing operations are permitted.
>
> R_3 is a second boom-restricted segment terminating at B.

The aircraft accelerates along R_1 from the initial speed of 500 ft/sec up to Mach 0.9. If the acceleration distance is shorter than R_1 then the aircraft continues at Mach 0.9 to the end of R_1. Within R_2 the aircraft accelerates from Mach 0.9 up to its design speed, cruises, and decelerates to Mach 0.9. Within R_3 the aircraft decelerates from Mach 0.9 to 500 ft/sec over the destination, B. If R_3 is longer than the required deceleration distance, i.e. the destination is some distance inland, the aircraft cruises at M0.9 for part of R_3 before decelerating.

R_1 and R_3 each include 10 miles of the 20-mile distance allowance noted above and all three segments include the 2%

allowance. If R_1 is shorter than the distance for the aircraft to accelerate to Mach 0.9 which could be the case for a route heading directly out from a shoreline airport, then the acceleration continues into R_2. If R_3 is short, it is treated in the same way.

If R_2, the available cruising distance, is not very long there may be insufficient distance for the aircraft to attain its design cruising speed and to decelerate. In this event, the aircraft accelerates until it reaches the midpoint then it decelerates to arrive at the end of R_2 at Mach 0.9 without having attained the design speed. For example, the distance from New York to Caracas is 1,837 nautical miles, but a Mach 8.0 aircraft requires 1,018 nautical miles for acceleration to cruising speed and the same distance for deceleration. Thus the aircraft would not attain Mach 8.0 on this particular city pair.

4. ROUTES AND TRAFFIC

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The projection of traffic flows for this study consisted of two principal elements - the identification of the markets to be served, and the projection of passenger traffic levels for these markets.

Identification of Markets

4.1 General Characteristics

It was assumed that very high speed transport aircraft would be commercially applied only to routes with some combination of the following characteristics:

- long range
- high traffic density
- extensive overwater legs
- coordination with other routes

Range is an important criterion for several reasons. As was pointed out in section 3.1, a Mach 4 aircraft covers 1,006 nautical miles in the acceleration and deceleration element of its flight profile; for a Mach 8 aircraft the distance is 2,036 nautical miles. Also, the shorter the segment, the more significant ground and air maneuver becomes in total block time, diluting the cruise speed advantage. This last element is even more material for the passenger, for whom the "block allowance" also includes access from his true origination point to his final destination plus check-in time.

A vehicle characteristic which complicated the market analysis portion of this study is the assumed unlimited range capability, opening up potential segments (e.g. London-Sydney) for which no specific historical data was available. True origin-to-destination traffic on such routes had to be inferred from analysis of such items as traffic flow on intermediate segments, of which there were generally a large number of possible combinations, and statistics of visitors to a country by country of citizenship or residence - here, too, judgment had to be applied since the multi-stop nature of many trips is desired, rather than required by lack of present non-stop capability.

Traffic density is important to allow a reasonable frequency of operations with an assumed several-hundred passenger capacity aircraft. Transportation is a service industry and as such needs to be available when desired on a daily basis.

The overwater requirement was not a limiting factor per se since the no sonic boom constraint configuration would not require any overwater operation. However, since both of the other constraint configurations required material overwater portions of the flight, this characteristic represents a plus factor for a route (e.g. Caracas - New York) which otherwise might not have been included.

The consideration of coordination with other routes is important from a commercial point of view. The more destinations that are served from a given point, the greater the flexibility that is possible for scheduling and routing and maintenance spares support.

4.2 Initial Selection

The first step in the process was the identification of existing scheduled segments which satisfied the general characteristics discussed above. This was accomplished through inspection of ICAO traffic flow statistics (Reference 4) and airline schedules (Reference 5). To these were added segments which, based on evaluation of communities of interest and review of other industry data and forecasts, were considered to represent potential markets for HST aircraft.

These city-pair routings were then consolidated by grouping together those proximate cities in any given region for which there may in fact be some current sharing of traffic due to existing schedule patterns, and for which the operational flight track and profile characteristics for approach and departure for HST aircraft would be similar. This grouping was done for the purpose of keeping the forecasting and scheduling analysis within workable bounds. In actual practice the aircraft would be operated by many airlines over segments connecting many more true origins and destinations, but the grouped approach used herein reasonably approximates the results.

For the purposes of this grouping process, it was assumed that the current principal traffic point in each area would be the HST operational site in the analysis, and that a radius of approximately 600 nautical miles represented the practical maximum analysis area which could be included without undue distortion of the operational results.

The initial list of city pairs thus selected for more in-depth traffic analysis, constituting 41 markets, is presented in Figure 4-1. The additional cities included in the grouping procedure are shown in Figure 4-2. It can be seen that London thus represents northwestern Europe, Madrid the Iberian peninsula, and Rome southeastern Europe. In North America, New York represents the northeast, Los Angeles the southwest, and Chicago the north central portion - the inclusion of Montreal with Chicago rather than New York is a compromise counterbalancing the fact that some of the traffic funneled through New York

Figure 4-1

INITIAL SELECTION OF CITY PAIR MARKETS AND GREAT CIRCLE DISTANCES*

Caracas - Madrid	3,779
Caracas - New York	1,837
Chicago - London	3,421
Delhi - London	3,630
Delhi - Moscow	2,353
Delhi - Sydney	5,626
Hong Kong - Honolulu	4,827
Hong Kong - London	5,202
Hong Kong - Los Angeles	6,280
Hong Kong - Sydney	3,978
Hong Kong - Tel Aviv	4,181
Honolulu - Los Angeles	2,200
Honolulu - New York	4,303
Honolulu - Sydney	4,419
Honolulu - Tokyo	3,325
Johannesburg - London	4,894
Johannesburg - New York	6,920
Lima - Los Angeles	3,623
London - Los Angeles	4,725
London - Miami	3,834
London - Nairobi	3,689
London - New York	2,988
London - Peking	4,406
London - Singapore	5,866
London - Sydney	9,178
London - Tokyo	5,173
Los Angeles - New York	2,143
Los Angeles - Singapore	7,609
Los Angeles - Sydney	6,505
Los Angeles - Tokyo	4,712
Madrid - New York	3,109
Madrid - Rio de Janeiro	4,394
Moscow - Tokyo	4,049
New York - Rio de Janeiro	4,169
New York - Rome	3,703
New York - Sydney	8,636
New York - Tel Aviv	4,917
New York - Tokyo	5,841
Singapore - Sydney	3,397
Singapore - Tokyo	2,893
Tokyo - Vancouver	4,048

* Distances in nautical miles as calculated by Speas Associates

Figure 4-2

CITY GROUPINGS FOR HST TRAFFIC FLOWS

Nominal City	Included Cities
Caracas	Bridgetown, Port of Spain, San Juan
Chicago	Detroit, Montreal, Toronto
Hong Kong	Manila
London	Amsterdam, Brussels, Cologne, Copenhagen, Frankfurt, Geneva, Hamburg, Paris, Zurich
Los Angeles	San Diego, San Francisco
Madrid	Lisbon
New York	Boston, Philadelphia, Washington
Rio de Janeiro	Sao Paulo
Rome	Athens, Milan
Singapore	Bangkok, Djakarta
Sydney	Melbourne
Tokyo	Osaka
Vancouver	Seattle

would actually find good Chicago service more convenient. In the Far East, the market radius was stretched to include Manila with Hong Kong and Bangkok with Singapore.

4.3 Projected Routings

Further analysis of the initial selection of markets concentrated on rationalization of true origin - destination flows of traffic, especially in those markets currently served only by numerous combinations of multi-stop routings. The following discussion of the Honolulu-Sydney market is an example of the kind of analysis undertaken, using ICAO traffic flows (Reference 4) and airline schedules as presented in the Official Airline Guide (Reference 5) as principal sources.

Between Honolulu and Sydney the schedules in September 1972 were as follows:

British Airways	LHR-JFK-LAX-HNL-NAN-SYD-MEL
Qantas	YVR-SFO-HNL-NAN-SYD-MEL
Air New Zealand	LAX-HNL-AKL-SYD
Pan American	LAX-HNL - SYD-HKG
Pan American	LAX-HNL-NAN-SYD-DPS-HKG
Pan American	LAX-HNL-NOU-SYD-MEL
CPAir	YVR HNL-NAN-SYD
American Airlines	CHI-HNL-NAN-SYD

Thus there were four ways to go from Honolulu to Sydney:

1. Non Stop
2. Via Nandi (NAN)
3. Via Auckland (AKL)
4. Via Noumea (NOU)

Using the ICAO traffic flows, the flight segment traffic by airline was analyzed for the four reported months of 1972 as shown in Figure 4-3.

Figure 4-3

TRAFFIC FLOWS ON SELECTED SEGMENTS FROM HONOLULU TO SYDNEY

	Mar 72	Jun 72	Sep 72	Dec 72	Estimated Year (4 Months x 3)
Nandi-Sydney					
Pan American	1,950	2,005	2,534	1,601	24,270
Qantas	3,981	5,273	7,834	5,062	66,450
British Airways	1,364	1,615	2,564	2,024	22,701
American Airlines	379	600	911	573	7,389
CPAir	253	216	416	205	3,270
Honolulu-Auckland					
Air New Zealand	656	939	1,737	1,917	15,747
Honolulu-Sydney					
Pan American	767	773	1,211	1,064	11,445
Noumea-Sydney					
Pan American	487	392	486	584	5,847

Source: ICAO Digest of Statistics - Traffic Flow

In Figure 4-4, these flows are further analyzed to estimate the amount of traffic which in fact desired to proceed directly from Honolulu to Sydney. The methodology followed the following steps.

On the Nandi-Sydney segment, local traffic at Nandi would not generate the majority of passengers to Australia. It is estimated that 65% of the 124,080 passengers were in transit at Nandi.

The fact that local national airlines are likely to generate more traffic between Nandi and Sydney than foreign airlines explains the difference in the estimated percentages between Pan American, American, Qantas on the one hand, and British Airways and CPAir on the other.

Of 124,000 passengers on this segment in 1972, 42,000 of them are assumed to have originated at Nandi, the balance of 82,000 are people who came from Honolulu and points beyond. Among the 82,000 passengers, the majority are estimated to have spent at least one day in Honolulu, either as residents or on planned business or vacation stopovers.

Again, the U.S. airlines and Qantas are likely to have the highest percentage of such traffic.

49,742 passengers are thus estimated to have departed Honolulu enroute to Australia via Nandi. Only Pan American continued its flights further than Australia, to Denpasar and Hong Kong, and it is estimated that only 30% of its passengers would not be disembarking at Sydney. This percentage is low because most people who go from the U.S. to Hong Kong can benefit from more

Figure 4-4

ESTIMATION OF TRUE HONOLULU-SYDNEY TRAFFIC

	Segment Passengers	Estimated Through Passengers		Estimated Originations at Honolulu		Estimated Destinations at Sydney	
NAN-SYD							
Pan Am	24,270	65%	15,775	65%	10,253	70%	7,178
Qantas	66,450	65%	43,192	65%	28,074	100%	28,074
British Airways	22,701	70%	15,830	45%	7,150	100%	7,150
American	7,389	65%	4,802	65%	3,121	100%	3,121
CPAir	3,270	70%	2,289	50%	1,144	100%	1,144
	124,080		81,888		49,742		46,667
HNL-SYD							
Pan Am	11,445	100%	11,445	65%	7,439	100%	7,439
HNL-AKL							
Air New Zealand	15,747	100%	15,747	55%	8,660	25%	2,215
NOU-SYD							
Pan Am	5,847	55%	3,216	65%	2,090	100%	2,090
Total	157,119		112,296		67,931		58,411

Source: Figure 4-3 and Speas Associates Analysis direct flights.

The final estimation of true non-stop O&D passengers from Honolulu to Sydney via Nandi is thus approximately 47,000 for calendar year 1972.

Similar analyses for the other segments resulted in the estimation of the 1972 total true O&D non-stop traffic between Honolulu and Sydney of 58,000 passengers.

Other sources which were used to complement and/or confirm the traffic flow volumes derived from the ICAO statistics were the U.S. Immigration and Naturalization Service, United Nations Statistical Yearbooks, various aircraft manufacturer surveys and forecasts, and tourist data published by several foreign countries.

These analyses led to the selection of the 22 markets presented in Figure 4-5, with the minimum size market included representing 120 daily one-way passengers. Figure 4-6 shows the routings graphically.

Although Peking had been presented in the initial selection, no data was found which would allow reliable quantification of the size of any of its markets, and so it was assumed for the purposes of this study that its service would be handled through Tokyo, less than 1,200 miles away.

Also, the selection of Singapore instead of Hong Kong as the southeast Asia gateway was judgmental and included consideration of geographic location vis-a-vis other routings. Both cities have strong communities of interest with the rest of the world, but Singapore's connections with Australia and

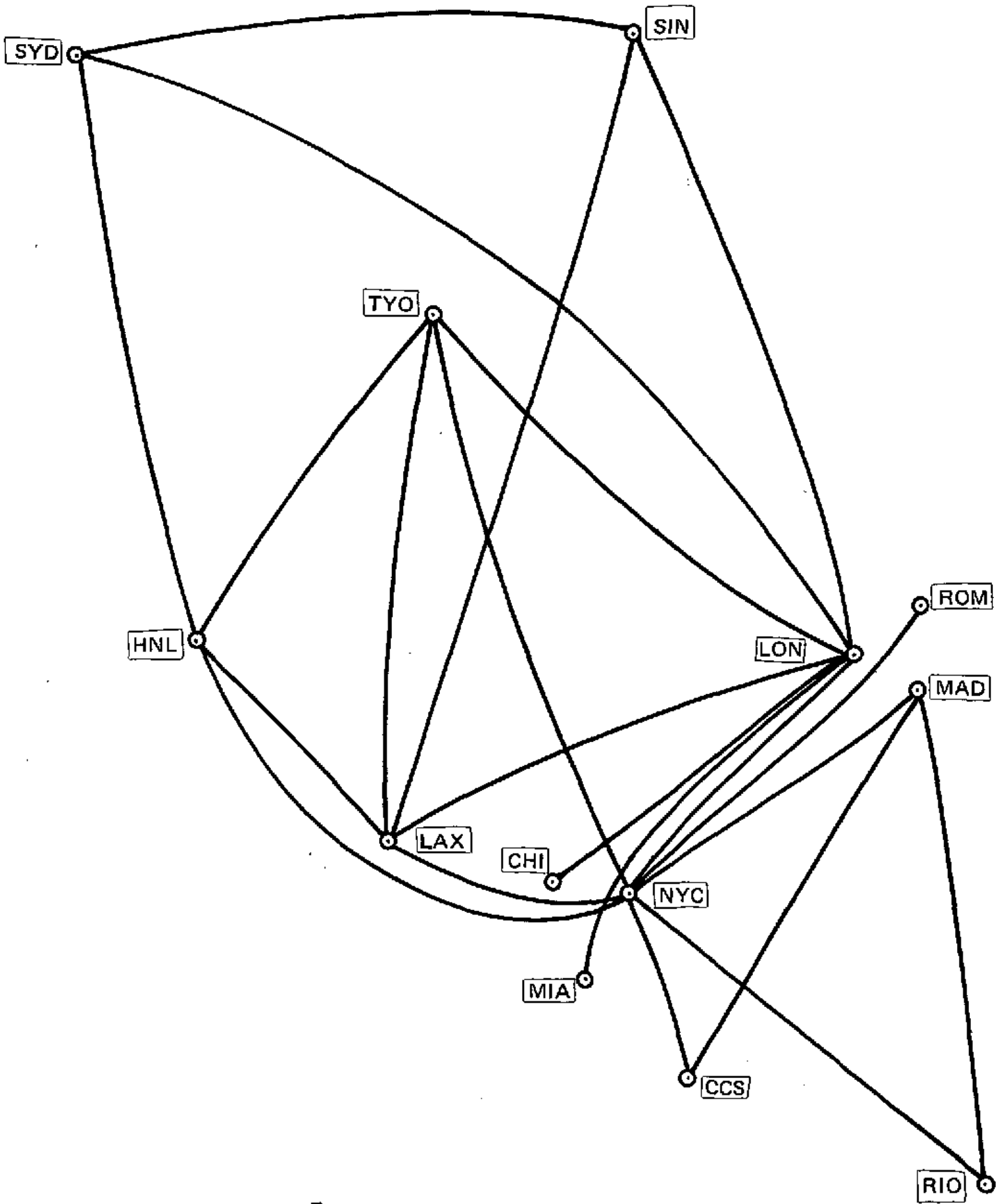
Figure 4-5

CITY PAIRS SELECTED FOR HST OPERATIONS

Final Selection of City Pairs	Great Circle Distance (n.mi.)	Estimated 1972 One-Way O&D Passengers (000)
Caracas - Madrid	3,779	43
Caracas - New York	1,837	132
Chicago - London	3,421	954
Honolulu - Los Angeles	2,200	374
Honolulu - New York	4,303	109
Honolulu - Sydney	4,419	58
Honolulu - Tokyo	3,325	130
London - Los Angeles	4,725	350
London - Miami	3,834	245
London - New York	2,988	1,700
London - Singapore	5,866	206
London - Sydney	9,178	80
London - Tokyo	5,173	146
Los Angeles - New York	2,143	1,468
Los Angeles - Singapore	7,609	71
Los Angeles - Tokyo	4,712	185
Madrid - New York	3,109	250
Madrid - Rio de Janeiro	4,394	55
New York - Rio de Janeiro	4,169	57
New York - Rome	3,703	400
New York - Tokyo	5,841	60
Singapore - Sydney	3,397	50

Figure 4-6

PROJECTED HST ROUTINGS FOR THE YEAR 2000



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the fact that Hong Kong is only 1,585 miles from Tokyo tipped the final balance in favor of Singapore.

4.4 Projections to the Year 2000

Compound growth rates varying from a low of 6% per year for the mature, domestic Los Angeles-New York market to a high of 8½% for the younger, longer range Far East markets have been applied to the estimated 1972 traffic flows to come up with projections for traffic for the year 2000. The resultant flows are presented in Figure 4-7.

These growth rates were selected after consideration of historical growth rates of traffic in the various countries and parts of the world, and review of existing industry forecasts.

As would be expected, the northeast U.S. to northwest Europe market, as represented by the city pair London-New York remains the number one market, but north central U.S. to northwest Europe (Chicago-London) passes Los Angeles-New York for second largest position.

By the year 2000 with the assumed growth rates, the market sizes considered range from a high of 35,000 one-way passengers per day in the London-New York market to a low of 900 per day in Caracas-Madrid, representing a 650% growth from 1972. In the faster growing routes to the Far East, the growth is almost 900%.

Figure 4-7

PROJECTION OF TRAFFIC FLOWS FOR HST OPERATIONS

Final Selection of City Pairs	Estimated 1972 One-Way O&D Passengers (000)	Assumed Compound Growth Rate 1972 - 2000 (Percent)	Estimated 2000 One-Way O&D Passengers (000)
Caracas - Madrid	43	7.5	330
Caracas - New York	132	8.0	1,140
Chicago - London	954	7.5	7,230
Honolulu - Los Angeles	374	7.5	2,830
Honolulu - New York	109	8.0	940
Honolulu - Sydney	58	8.5	570
Honolulu - Tokyo	130	8.5	1,280
London - Los Angeles	350	8.0	3,020
London - Miami	245	7.5	1,860
London - New York	1,700	7.5	12,880
London - Singapore	206	8.5	2,020
London - Sydney	80	8.5	790
London - Tokyo	146	8.5	1,430
Los Angeles - New York	1,468	6.0	7,080
Los Angeles - Singapore	71	8.5	700
Los Angeles - Tokyo	185	8.5	1,820
Madrid - New York	250	7.5	1,890
Madrid - Rio de Janeiro	55	7.5	420
New York - Rio de Janeiro	57	8.0	490
New York - Rome	400	7.5	3,030
New York - Tokyo	60	8.5	590
Singapore - Sydney	50	8.0	430

Source: Speas Associates Analysis

5. SELECTION OF FLIGHT TRACKS

For each of the city pairs of interest, flight tracks were selected according to the aircraft performance capabilities (acceleration and turns) and in compliance with the sonic boom constraints. The aircraft were not assumed to fly along the present systems of organized ATC tracks which generally follow straight line segments between successive navigational check points and which sometimes deviate significantly from the most direct path.

5.1 Sonic Boom Considerations

(a) No Boom Constraints

In the case of the aircraft without sonic boom constraints, the flight tracks were selected as the great circles connecting the cities. The flight distance would then be the great circle distance plus the maneuver allowances noted previously.

(b) Strict Boom Constraints

In the case of the aircraft with the strict sonic boom constraints, all supersonic flights had to be confined to over-water areas. A sonic boom "corridor" of 50 miles total width (25 miles on each side of the flight track) was specified by NASA, so that the selected tracks thus observed a 25-mile "buffer" around all land areas. The only exception to the sonic boom constraint was Antarctica where supersonic overflights were allowed. Depending on the particular city pair, some flight operations included significant amounts of time in subsonic operation and/or substantial increases in flight distances in order to avoid land areas. For example, the track selected for a flight from Chicago to London would require that the aircraft cruise at Mach 0.9 until it reached the Atlantic Ocean at a point just south of New York. It would then accelerate and cruise enroute, staying sufficiently off shore from Nantucket and Cape Race, then decelerate again to Mach 0.9 before entering the English Channel and then cruise subsonically to London.

(c) Mixed Boom Constraints

For the third type of aircraft the boom constraints were relaxed to allow steady supersonic cruise over land, but the flight tracks had to stay over water areas for both the acceleration and deceleration phases. This "maneuvering room" requirement was very large for the high-mach-number vehicles because turning capability was sharply limited and the acceleration distance was also very long. The block time for some city pairs did not improve very much with this relaxation of the sonic boom constraints whereas the block times for other city pairs improved substantially.

Typical of those which realized little improvement would be the city pairs where the track would be over water in any case (such as Los Angeles-Tokyo or Sydney-Honolulu) or the cases like Chicago-London where there was insufficient area available for acceleration near both end points (Lake Michigan is too small for this purpose). On the other hand, this relaxation was beneficial for flights from New York to Rome where the Mediterranean Sea afforded sufficient room for deceleration so that the aircraft could traverse the Iberian peninsula at the design cruising speed and very little subsonic operation would be required.

5.2 Selection of "Best" Tracks

As noted above, in the absence of sonic boom constraints the great circle tracks were chosen since they are clearly the shortest in time and distance (and thus the lowest cost). With the sonic boom constraints imposed, some city pairs could still be connected by tracks that did not deviate far from the great circle.

For some other city pairs the deviations could become very large if the tracks adhered only to oceans or if the track selection was based only on minimum block time.

As an example, consider the selection of the best track from Singapore to Sydney for aircraft which must comply with strict overland boom constraints. Four alternative routings were examined, all of which began by a subsonic crossing of Sumatra in a southwesterly direction to the Indian Ocean, then:

(1) supersonic flight south of the Indonesian archipelago to a landfall southwest of Darwin and subsonic flight overland to Sydney (3,738 n. mi.)

(2) a slightly shorter, more direct flight track south of (1) above but requiring a longer portion over land (3,578 n. mi.)

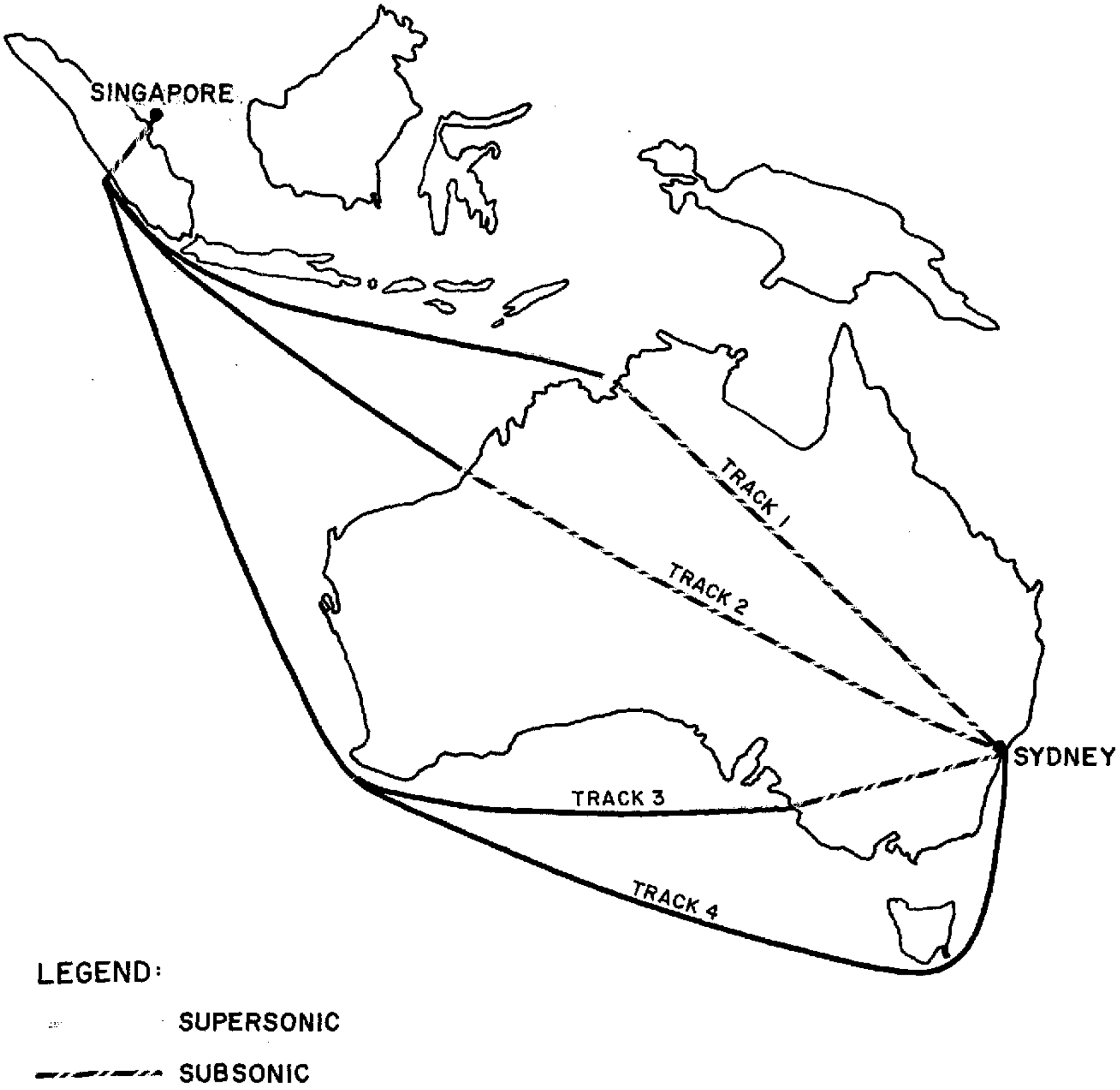
(3) supersonic flight around western Australia to a landfall south of Adelaide and subsonic flight overland to Sydney (4,107 n. mi.)

(4) supersonic flight around western Australia and south of Tasmania, approaching Sydney over water from the south (4,618 n. mi.)

These tracks are illustrated in Figure 5-1.

Figure 5-1

SELECTION OF ALTERNATIVE FLIGHT TRACKS
SINGAPORE TO SYDNEY



Note that the Bass Strait between Australia and Tasmania contains islands which rule out the availability of a supersonic corridor. Block time analysis showed that all aircraft with design Mach numbers of 2.0 or greater could fly the longest routing in less block time than any of the other three routings. The shortest route, number 2, would require the most time. However, rather than make the track selection solely on the basis of least time or least distance, Speas Associates chose a methodology that would be more representative of a selection based on minimum cost.

A recent NASA report (NASA CR-2286, "A Methodology for Hypersonic Transport Technology Planning", Sept. 1973) showed the following operating costs for a representative HST aircraft:

Cost Element	¢/Ton Mile
Fuel	25.7
Crew	1.0
Insurance	2.1
Depreciation	12.0
Maintenance	6.0
Total	46.8

Thus, about one-half of the operating cost is accounted for by fuel. Earlier studies of SST operations indicated that the mission fuel requirement for a particular aircraft was not very sensitive to variations in the amount of the mission distance flown supersonically. That is, the L/D and SFC at subsonic and supersonic speeds were such that the overall fuel mileage (miles per pound) would be about the same in either case. Hence, the fuel cost would be most closely related to the total distance flown and not much affected by the division between subsonic and supersonic portions of the total trip.

The other cost elements, crew, insurance, depreciation and maintenance tend to be most closely associated with the actual operating time. Thus, about 50% of a typical mission cost would be proportional to the distance flown and the other 50% proportional to the block time. Speas Associates, assumed that the nominal HST mission is 5,000 nautical miles over water. For this mission it is convenient to assign a cost of 10,000 cost units (not necessarily dollars), and thus the two cost elements would be 5,000 units for fuel (one unit per mile) and 5,000 units for the time-related factors. With these cost-per-mile and cost-per-hour elements known, it is then possible to determine the economic trade-offs between time and distance for each particular design speed. For example, a Mach 4 transport can perform the nominal 5,000 mile mission over water in 2.84 hours using the block time methodology described above. Thus, its operating costs are:

Total cost = (5,000/5,000) units per mile plus (5,000/2.84) units per hour
= 1 unit per mile plus 1,761 units per hour.

These unit costs can then be used to compare the relative costs of the alternative flight tracks for the Mach 4 transport. Using the four Singapore-Sydney tracks the cost comparison would be:

	Route #1	Route #2	Route #3	Route #4
Miles	3,738	3,578	4,107	4,618
Hours	5.45	5.59	4.01	3.32
Mileage cost	3,738	3,578	4,107	4,618
Hourly cost	9,597	9,844	7,062	5,847
Total Cost	13,335	13,422	11,169	10,465

Thus, for a Mach 4 HST the longest (but least-time) route would be the most economical. Similar calculations were made across the entire spectrum of Mach numbers being used in this analysis, and it was found that Route #3 would be most economical for design speeds between Mach 2.0 and 2.7. Above Mach 2.7 the long overwater route would be most economical by virtue of its substantial time-saving potential.

This same methodology was applied wherever there appeared to be potential time savings available by increasing the amount of overwater distance in the routing.

5.3 Discussion of Individual City-Pair Tracks

Tracks for each of the selected city pairs were plotted on Global Navigation Charts which provide coverage of the entire world on 26 overlapping sheets at a scale of about 68 nautical miles to the inch. Other standard aeronautical and nautical charts were used for certain detailed references where necessary.

Following is a brief description of the tracks selected for each city pair.

1. Caracas-Madrid

The Windward and Leeward Islands comprise an almost continuous chain enclosing the Caribbean Sea. The only gap wide enough to accommodate a fifty-mile supersonic corridor is the Anegada Passage between Anguilla and the Virgin Islands. Strict boom constraints would require aircraft to fly via this passage. Under mixed boom constraints allowing steady cruising flight over land, a more direct route passing over the island chain near Guadeloupe may be used provided the aircraft can attain its cruising speed before reaching Guadeloupe. This is the case for aircraft with design speeds up to Mach 3. Faster aircraft would still be accelerating as they cross Guadeloupe on this track, so they would be obliged to use the Anegada Passage routing. The European landfall would be at a point a few miles south of Lisbon.

2. Caracas-New York

The track selection for this city pair is similar to that for Caracas-Madrid. Under strict sonic boom constraints or for aircraft whose acceleration distance cannot be accommodated between Caracas and the Indies, the track goes through the Anegada Passage. Under mixed boom constraints the direct track passes over Mona Island, and this is usable by aircraft of design Mach numbers of 3.0 or less.

3. Chicago-London

The track selected proceeds subsonically over land to reach the Atlantic about 25 miles south of New York then directly across the Atlantic skirting Nantucket and Cape Race into the English Channel between Brest and Lands End then subsonically to London.

4. Honolulu-Los Angeles

This flight is almost entirely over water except for a short segment at each end to provide clearance from nearby islands.

5. Honolulu-New York

With strict boom constraints the supersonic portion of this flight extends from Honolulu to a landfall just south of San Diego followed by a direct subsonic flight over land to New York. With mixed boom constraints the aircraft could proceed directly from Honolulu across the continental United States and then decelerate offshore over the Atlantic. The track varies with Mach number so that the arrival over the Atlantic is south of New York a sufficient distance to just accommodate a turning, decelerating segment. For example, a Mach 5 HST which would require about 630 miles for deceleration would fly from Honolulu directly to a point over the Atlantic offshore from Charleston S.C. where it would begin the descending, decelerating turn toward New York.

6. Honolulu-Sydney

This flight is almost entirely over water except for short segments at each end. Boom constraints are not significant.

7. Honolulu-Tokyo

Same as Honolulu-Sydney above.

8. Los Angeles-London

Under strict boom constraints there are three general choices for flight tracks. The first is an essentially all-supersonic flight southward around Cape Horn then northward over the Atlantic. This track is faster for aircraft designed for Mach 5 or more but not surprisingly it was found to be uneconomical because of the great distance (over 13,000 nautical miles). The second, a polar route through the

Aleutians and the Bering Strait, is not available if a 50-mile corridor is to be observed. The third route, and the one chosen for the analysis requires a transcontinental flight of about 1,890 nautical miles to the Atlantic near Brunswick, Georgia and a supersonic flight of about 3,510 nautical miles ending at the entrance to the English Channel, then a short subsonic segment to London.

With mixed boom constraints the acceleration to cruising speed would be made while proceeding north off the California coast. For design Mach numbers of 4.0 or lower the supersonic cruise should terminate at the entrance to the English Channel. Above Mach 4 there is a slight advantage in approaching London from the north, decelerating over the North Sea. The advantage arises because this route, while longer overall, involves a shorter subsonic segment at the London end.

9. Los Angeles-New York

Under strict boom constraints this flight would be simply a subsonic direct flight over land. With mixed boom constraints however, a profile like that suggested by Becker and Kirkham in Reference 2 could be used. This involves an accelerating turn over the ocean at one end and a similar decelerating turn at the other end. On the west coast, the landfall penetration point moves southward with increasing vehicle design Mach number, being about halfway down the Baja California peninsula for Mach 5 and reaching the tip for Mach 8. The east coast transition point would be near Brunswick, Georgia for Mach 6 to 8, moving progressively north for lower Mach numbers so that in all cases the deceleration ends about 30 miles south of New York.

10. Los Angeles-Singapore

    Operations on this city pair would be only slightly affected by sonic boom constraints. With strict constraints the track would pass over the Luzon Strait between the Philippines and Formosa and this would imply relatively little added mileage. With mixed constraints the track would be slightly farther south, passing over the Philippines.

11. Los Angeles-Tokyo

    This flight would be almost entirely over water and would be little affected by sonic boom rules.

12. London-Miami

    This would be a direct supersonic flight except for a subsonic segment from London to the opening of the English Channel.

13. London-New York

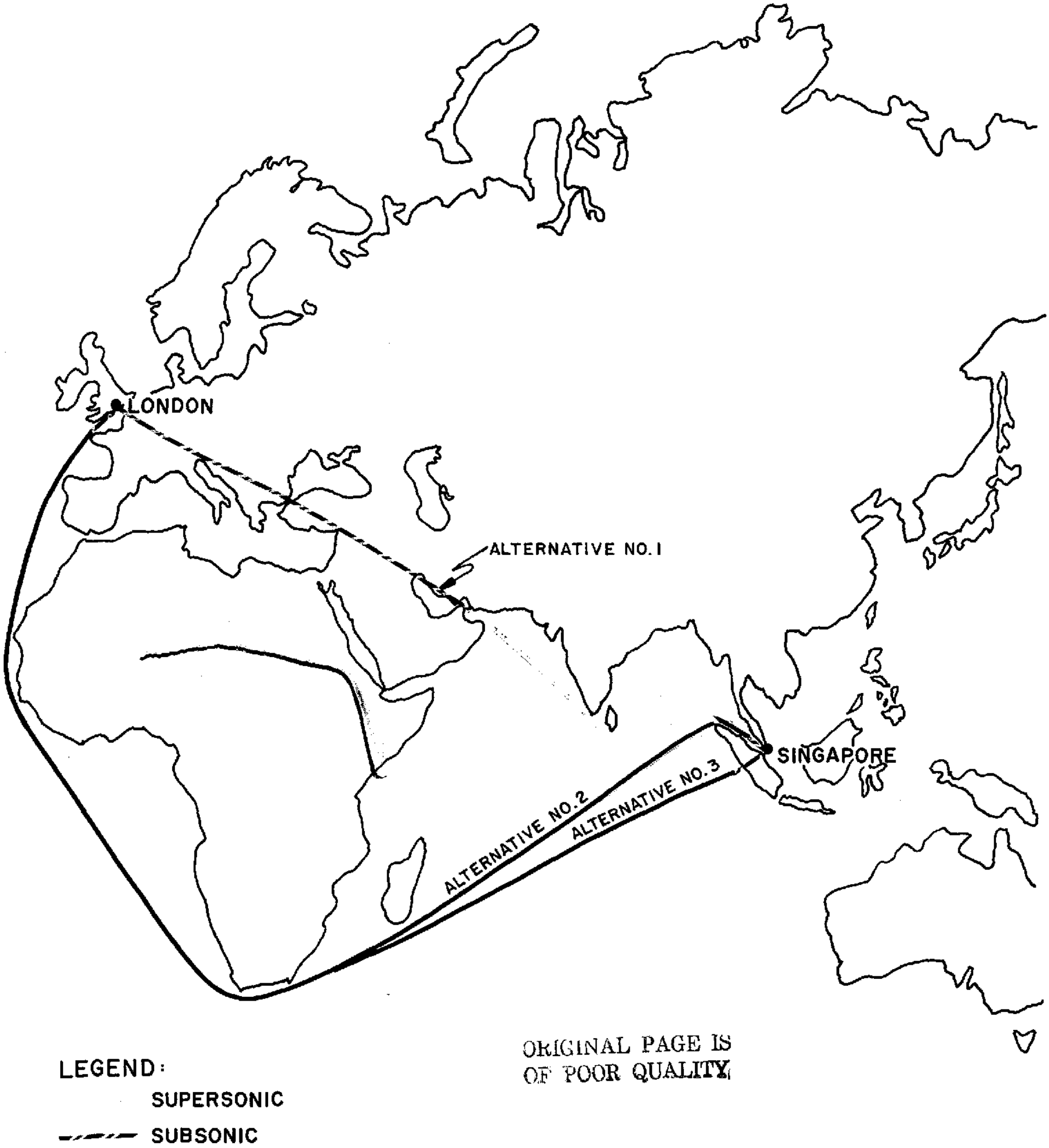
    See comments above for London-Miami,

14. London-Singapore

    Under strict sonic boom constraints the tracks examined are those shown in Figure 5-2. The longest route (number 3) around Africa would be the fastest for all aircraft speeds above Mach 2.5, however, it is not the most economical until the design Mach number is greater than 5.0. Up to

Figure 5-2

SELECTION OF ALTERNATIVE FLIGHT TRACKS
LONDON TO SINGAPORE



Mach 5.0 the shorter subsonic flight across Europe with the supersonic segment over the Indian Ocean would be the best track.

With mixed constraints a turning acceleration over the North Sea would be made after departure from London followed by cruising flight mostly over land. Deceleration would begin over the Bay of Bengal and terminate in the Strait of Malacca

15. London-Sydney

The track selected for the strict boom constraint case would proceed down the Atlantic coast of Africa and then go directly from a point off Dakar following a great circle track to Sydney, which passes southward across part of Antarctica and then northward past the east coast of Tasmania, a total distance of about 12,000 nautical miles.

With mixed constraints the acceleration would be made over the North Sea; then the aircraft would proceed southeasterly and transition to deceleration off the east coast of Australia north of Sydney a distance equal to the required deceleration distance.

16. London-Tokyo

With strict sonic boom constraints this would be a polar flight with the supersonic acceleration beginning over the North Sea and the deceleration ending over the Laptev Sea north of Siberia. The remainder of the trip southward over Siberia would be flown subsonically.

With mixed constraints the supersonic acceleration would again begin while proceeding north over the North Sea. Deceleration would take place in a sweeping turn over the Pacific northeast of Tokyo.

17. Madrid-Rio de Janeiro

This flight is largely over water. Between Madrid and the Atlantic there is a subsonic segment of 265 nautical miles and there is another 125 mile segment from the vicinity of Campos into Rio. With strict boom constraints the aircraft must diverge slightly from the most direct route to avoid overflying the Canary and Cape Verde Islands.

18. Madrid-New York

This flight track follows the great circle between Madrid and Nantucket. The first 280 nautical miles from Madrid to the Atlantic are over land.

19. New York-Rio de Janeiro

With strict boom constraints the aircraft would go around eastern Brazil near Recife and decelerate to Mach 0.9 as it comes abeam Campos just north of Rio.

With mixed constraints the overall path length can be shortened by allowing the track to pass over eastern Brazil and then out over the south Atlantic at a distance along the east coast to allow deceleration in the remaining distance to Rio.

20. New York-Rome

With strict boom constraints the supersonic portion of this flight is over the Atlantic between New York and a point off Bordeau France and the remaining distance would be flown at subsonic speed.

With mixed constraints and with aircraft whose design Mach number is 7.0 or less, the supersonic portion of the track would extend onward across France and Spain and the deceleration would take place over the Mediterranean. The deceleration corridor must be selected with care and turns will be required to avoid islands and the Mediterranean shore line. Aircraft above Mach 7.0 would be unable to decelerate within the confines of the western Mediterranean, and hence these would revert to the track selected in the strict case.

21. New York-Tokyo

With strict boom constraints, the best flight track was determined to be a subsonic flight across the U.S. to the Pacific Ocean near Portland, Oregon, then a direct supersonic flight to Tokyo.

With mixed constraints, the aircraft should accelerate while heading north along the east coast of the U.S. and Canada then turn inland and fly directly across northern Canada and Alaska to Tokyo.

22. Singapore-Sydney

The track selection for this city pair was discussed earlier as the example illustrating the selection methodology.

5.4 City-Pair Block Times

HST block times were computed for each city pair and for each of the three sonic boom constraints over a range of vehicle design speeds from Mach 2.0 up to Mach 8.0. These block times are tabulated in Figures 5-3, 5-4, and 5.5. Figure 5-3 applies to the unrestricted case, Figure 5-4 applies to the fully restricted case (no supersonic flight over land) and Figure 5-5 applied to the mixed restriction (no supersonic acceleration or deceleration over land).

Figure 5-3

HST INTERCITY BLOCK TIMES (hours)
- No Sonic Boom Constraints -

HST INTERCITY BLOCK TIMES (HOURS)

FROM	TO	M0.9	M2.0	M3.0	M4.0	M5.0	M6.0	M7.0	M8.0
CCS	MAD	7.70	3.86	2.83	2.32	2.01	1.80	1.66	1.55
CCS	NYC	3.99	2.19	1.71	1.48	1.34	1.25	1.18	1.13
CHI	LON	7.02	3.55	2.62	2.16	1.88	1.70	1.57	1.47
HNL	LAX	4.68	2.50	1.92	1.64	1.46	1.35	1.27	1.21
HNL	NYC	8.70	4.31	3.13	2.54	2.19	1.95	1.78	1.66
HNL	SYD	8.93	4.41	3.20	2.59	2.23	1.99	1.81	1.69
HNL	TYO	6.83	3.47	2.57	2.12	1.85	1.67	1.54	1.45
LAX	HNL	4.68	2.50	1.92	1.64	1.46	1.35	1.27	1.21
LAX	LON	9.51	4.68	3.37	2.72	2.33	2.07	1.89	1.75
LAX	NYC	4.57	2.45	1.89	1.61	1.44	1.33	1.25	1.20
LAX	NYC	5.19	2.73	2.08	1.75	1.56	1.43	1.33	1.27
LAX	SIN	15.03	7.16	5.03	3.96	3.33	2.90	2.60	2.37
LAX	TYO	9.49	4.67	3.36	2.72	2.33	2.07	1.89	1.75
LON	CHI	7.02	3.55	2.62	2.16	1.88	1.70	1.57	1.47
LON	LAX	9.51	4.68	3.37	2.72	2.33	2.07	1.89	1.75
LON	MIA	7.81	3.91	2.86	2.34	2.03	1.82	1.67	1.56
LON	NYC	6.19	3.18	2.38	1.97	1.73	1.58	1.46	1.38
LON	SIN	11.69	5.66	4.03	3.21	2.73	2.40	2.17	2.00
LON	SYD	18.03	8.51	5.93	4.64	3.87	3.35	2.98	2.71
LON	TYO	10.37	5.06	3.63	2.92	2.49	2.20	2.00	1.85
MAD	CCS	7.70	3.86	2.83	2.32	2.01	1.80	1.66	1.55
MAD	NYC	6.42	3.29	2.44	2.03	1.78	1.61	1.49	1.41
MAD	RIO	8.88	4.39	3.18	2.58	2.22	1.98	1.81	1.68
MIA	LON	7.81	3.91	2.86	2.34	2.03	1.82	1.67	1.56
NYC	CCS	3.99	2.19	1.71	1.48	1.34	1.25	1.18	1.13
NYC	HNL	8.70	4.31	3.13	2.54	2.19	1.95	1.78	1.66
NYC	LAX	4.57	2.45	1.89	1.61	1.44	1.33	1.25	1.20
NYC	LON	6.19	3.18	2.38	1.97	1.73	1.58	1.46	1.38
NYC	MAD	6.42	3.29	2.44	2.03	1.78	1.61	1.49	1.41
NYC	RIO	8.45	4.20	3.05	2.48	2.14	1.91	1.75	1.63
NYC	ROM	7.56	3.80	2.79	2.28	1.98	1.78	1.64	1.53
NYC	TYO	11.65	5.64	4.01	3.20	2.72	2.39	2.16	1.99
RIO	MAD	8.88	4.39	3.18	2.58	2.22	1.98	1.81	1.68
RIO	NYC	8.45	4.20	3.05	2.48	2.14	1.91	1.75	1.63
ROM	NYC	7.56	3.80	2.79	2.28	1.98	1.78	1.64	1.53
SIN	LAX	15.03	7.16	5.03	3.96	3.33	2.90	2.60	2.37
SIN	LON	11.69	5.66	4.03	3.21	2.73	2.40	2.17	2.00
SIN	SYD	6.97	3.53	2.61	2.15	1.88	1.69	1.56	1.47
SYD	HNL	8.93	4.41	3.20	2.59	2.23	1.99	1.81	1.69
SYD	LON	18.03	8.51	5.93	4.64	3.87	3.35	2.98	2.71
SYD	SIN	6.97	3.53	2.61	2.15	1.88	1.69	1.56	1.47
TYO	HNL	6.83	3.47	2.57	2.12	1.85	1.67	1.54	1.45
TYO	LAX	9.49	4.67	3.36	2.72	2.33	2.07	1.89	1.75
TYO	LON	10.37	5.06	3.63	2.92	2.49	2.20	2.00	1.85
TYO	NYC	11.65	5.64	4.01	3.20	2.72	2.39	2.16	1.99

Source: Speas Associates Analysis

Figure 5-4

HST INTERCITY BLOCK TIMES (hours)
- Strict Sonic Boom Constraints -

HST INTERCITY BLOCK TIMES (HOURS)

FROM TO	M0.9	M2.0	M3.0	M4.0	M5.0	M6.0	M7.0	M8.0
CCS MAD	7.70	4.30	3.37	2.91	2.64	2.45	2.33	2.23
CCS NYC	4.18	2.35	1.90	1.68	1.55	1.46	1.40	1.36
CHI LON	7.02	4.67	3.90	3.53	3.30	3.16	3.05	2.97
HNL LAX	4.68	2.60	2.07	1.82	1.67	1.57	1.49	1.44
HNL NYC	8.70	6.56	6.01	5.74	5.58	5.48	5.40	5.35
HNL SYD	8.93	4.41	3.23	2.64	2.29	2.06	1.90	1.77
HNL TYO	6.83	3.66	2.80	2.38	2.13	1.96	1.84	1.75
LAX HNL	4.68	2.60	2.07	1.82	1.67	1.57	1.49	1.44
LAX LON	9.51	7.55	6.61	6.15	5.87	5.69	5.56	5.46
LAX NYC	4.57	4.47	4.45	4.44	4.43	4.42	4.41	4.41
LAX SIN	15.03	7.29	5.18	4.13	3.51	3.09	2.80	2.58
LAX TYO	9.49	4.79	3.53	2.91	2.54	2.30	2.12	1.99
LON CHI	7.02	4.67	3.90	3.53	3.30	3.16	3.05	2.97
LON LAX	9.51	7.55	6.61	6.15	5.87	5.69	5.56	5.46
LON MIA	7.81	4.15	3.15	2.66	2.37	2.17	2.03	1.93
LON NYC	6.19	3.46	2.69	2.31	2.09	1.94	1.84	1.76
LON SIN	11.69	9.36	8.53	8.12	7.88	4.65	4.19	3.85
LON SYD	18.03	11.13	7.81	6.15	5.16	4.50	4.03	3.68
LON TYO	10.37	7.71	6.86	6.44	6.19	6.03	5.91	5.82
MAD CCS	7.70	4.30	3.37	2.91	2.64	2.45	2.33	2.23
MAD NYC	6.42	3.58	2.83	2.47	2.25	2.11	2.01	1.93
MAD RIO	8.88	4.87	3.75	3.19	2.86	2.65	2.49	2.37
MIA LON	7.81	4.15	3.15	2.66	2.37	2.17	2.03	1.93
NYC CCS	4.18	2.35	1.90	1.68	1.55	1.46	1.40	1.36
NYC HNL	8.70	6.56	6.01	5.74	5.58	5.48	5.40	5.35
NYC LAX	4.57	4.47	4.45	4.44	4.43	4.42	4.41	4.41
NYC LON	6.19	3.46	2.69	2.31	2.09	1.94	1.84	1.76
NYC MAD	6.42	3.58	2.83	2.47	2.25	2.11	2.01	1.93
NYC RIO	8.45	4.82	3.56	2.94	2.57	2.32	2.15	2.02
NYC ROM	7.56	4.50	3.68	3.29	3.05	2.89	2.78	2.70
NYC TYO	11.65	8.35	7.26	6.72	6.40	6.19	6.03	5.92
RIO MAD	8.88	4.87	3.75	3.19	2.86	2.65	2.49	2.37
RIO NYC	8.45	4.82	3.56	2.94	2.57	2.32	2.15	2.02
ROM NYC	7.56	4.50	3.68	3.29	3.05	2.89	2.78	2.70
SIN LAX	15.03	7.29	5.18	4.13	3.51	3.09	2.80	2.58
SIN LON	11.69	9.36	8.53	8.12	7.88	4.65	4.19	3.85
SIN SYD	6.97	5.21	3.88	3.32	2.99	2.77	2.62	2.50
SYD HNL	8.93	4.41	3.23	2.64	2.29	2.06	1.90	1.77
SYD LON	18.03	11.13	7.81	6.15	5.16	4.50	4.03	3.68
SYD SIN	6.97	5.21	3.88	3.32	2.99	2.77	2.62	2.50
TYO HNL	6.83	3.66	2.80	2.38	2.13	1.96	1.84	1.75
TYO LAX	9.49	4.79	3.53	2.91	2.54	2.30	2.12	1.99
TYO LON	10.37	7.71	6.86	6.44	6.19	6.03	5.91	5.82
TYO NYC	11.65	8.35	7.26	6.72	6.40	6.19	6.03	5.92

Source: Speas Associates Analysis

Figure 5-5

HST INTERCITY BLOCK TIMES (hours)
- Mixed Sonic Boom Constraints -

HST INTERCITY BLOCK TIMES (HOURS)

FROM	TO	M0.9	M2.0	M3.0	M4.0	M5.0	M6.0	M7.0	M8.0
CCS	MAD	7.70	4.17	3.25	2.91	2.64	2.45	2.33	2.23
CCS	NYC	3.99	2.26	1.90	1.68	1.55	1.46	1.40	1.36
CHI	LON	7.02	4.67	3.90	3.53	3.30	3.16	3.05	2.97
HNL	LAX	4.68	2.60	2.07	1.82	1.67	1.57	1.49	1.44
HNL	NYC	8.70	4.53	3.41	2.82	2.47	2.24	2.09	1.98
HNL	SYD	8.93	4.41	3.23	2.64	2.29	2.06	1.90	1.77
HNL	TYO	6.83	3.66	2.80	2.38	2.13	1.96	1.84	1.75
LAX	HNL	4.68	2.60	2.07	1.82	1.67	1.57	1.49	1.44
LAX	LON	9.51	5.17	3.91	3.22	2.79	2.54	2.37	2.23
LAX	NYC	4.57	2.87	2.38	2.11	1.92	1.80	1.73	1.68
LAX	SIN	15.03	7.25	5.15	4.12	3.49	3.08	2.79	2.57
LAX	TYO	9.49	4.79	3.53	2.91	2.54	2.30	2.12	1.99
LON	CHI	7.02	4.67	3.90	3.53	3.30	3.16	3.05	2.97
LON	LAX	9.51	5.17	3.91	3.22	2.79	2.54	2.37	2.23
LON	MIA	7.81	4.15	3.15	2.66	2.37	2.17	2.03	1.93
LON	NYC	6.19	3.46	2.69	2.31	2.09	1.94	1.84	1.76
LON	SIN	11.69	5.83	4.35	3.61	3.53	3.22	3.14	2.96
LON	SYD	18.03	8.82	6.23	4.94	4.17	3.65	3.29	3.01
LON	TYO	10.37	5.41	3.97	3.25	2.90	2.64	2.46	2.32
MAD	CCS	7.70	4.17	3.25	2.91	2.64	2.45	2.33	2.23
MAD	NYC	6.42	3.58	2.83	2.47	2.25	2.11	2.01	1.93
MAD	RIO	8.88	4.80	3.70	3.16	2.84	2.62	2.47	2.35
MIA	LON	7.81	4.15	3.15	2.66	2.37	2.17	2.03	1.93
NYC	CCS	3.99	2.26	1.90	1.68	1.55	1.46	1.40	1.36
NYC	HNL	8.70	4.53	3.41	2.82	2.47	2.24	2.09	1.98
NYC	LAX	4.57	2.87	2.38	2.11	1.92	1.80	1.73	1.68
NYC	LON	6.19	3.46	2.69	2.31	2.09	1.94	1.84	1.76
NYC	MAD	6.42	3.58	2.83	2.47	2.25	2.11	2.01	1.93
NYC	RIO	8.45	4.55	3.41	2.83	2.52	2.28	2.15	2.02
NYC	ROM	7.56	4.02	3.01	2.48	2.17	2.01	1.85	2.70
NYC	TYO	11.65	5.93	4.34	3.55	3.04	2.73	2.53	2.36
RIO	MAD	8.88	4.80	3.70	3.16	2.84	2.62	2.47	2.35
RIO	NYC	8.45	4.55	3.41	2.83	2.52	2.28	2.15	2.02
ROM	NYC	7.56	4.02	3.01	2.48	2.17	2.01	1.85	2.70
SIN	LAX	15.03	7.25	5.15	4.12	3.49	3.08	2.79	2.57
SIN	LON	11.69	5.83	4.35	3.61	3.53	3.22	3.14	2.96
SIN	SYD	6.97	4.03	3.02	2.52	2.22	2.01	1.86	1.74
SYD	HNL	8.93	4.41	3.23	2.64	2.29	2.06	1.90	1.77
SYD	LON	18.03	8.82	6.23	4.94	4.17	3.65	3.29	3.01
SYD	SIN	6.97	4.03	3.02	2.52	2.22	2.01	1.86	1.74
TYO	HNL	6.83	3.66	2.80	2.38	2.13	1.96	1.84	1.75
TYO	LAX	9.49	4.79	3.53	2.91	2.54	2.30	2.12	1.99
TYO	LON	10.37	5.41	3.97	3.25	2.90	2.64	2.46	2.32
TYO	NYC	11.65	5.93	4.34	3.55	3.04	2.73	2.53	2.36

Source: Speas Associates Analysis

6. AIRCRAFT SCHEDULING

6.1 Introduction

In order to explore the possible application of HST aircraft on world-wide route networks, a scheduling analysis was made based on the traffic forecasts developed in Section 4 of this report. The intent of this analysis was two-fold:

1) to determine the extent to which overland sonic boom constraints would limit the potential aircraft productivity, and

2) to see whether or not the combined circumstances of widespread airport curfews and short flight times would be an impediment to efficient aircraft scheduling.

6.2 Transit and Turnaround Times

NASA specified to R. Dixon Speas Associates that the transit and turnaround times that would be required for a commercial HST aircraft in regular operations would be essentially the same as those required for the present generation of large, subsonic jets.

A number of factors bear on and affect ground handling times of large aircraft operated in passenger service. These fall into two principal categories, namely operations and customer service.

Operational functions include:

- ground support equipment positioning and functioning
- fueling
- aircraft inspection and line service
- preflight preparation and checks
- aircraft positioning (including parking and push outs)
- engine shut downs and starts

Customer service items include:

- passenger deplaning and enplaning
- baggage loading and unloading
- cargo loading and unloading
- commissary loading and unloading
- aircraft cleaning and provisioning

In addition, certain international flights must meet varying international procedural requirements including:

- public health inspection of aircraft prior to deplaning
- presentation of aircraft load documentation prior to deplaning
- supervision of loading and unloading functions by customs, immigration and public health officials

As is apparent from the items listed above, the time involved in carrying out any particular function is dependent upon the quantity and quality of both equipment and personnel available. For example, a high volume hydrant fueling system would be greatly superior in terms of time saved to refuel by truck. An adequate number of baggage carts and tractors permitting loading and unloading operations simultaneously would speed up baggage and cargo handling by a factor of two.

To determine actual ground handling times now scheduled and experienced by major U.S. airlines, the scheduling departments of several airlines were contacted. Additionally, pertinent schedules of major carriers were reviewed for supporting information. All carriers have conducted detailed analyses of ground handling functions and have based schedules on those analyses after tempering results with practical considerations.

In domestic services ground handling times for wide bodied aircraft are primarily limited by baggage handling functions. For transit stations a representative objective is 45 to 55 minutes. At major stations where 747 aircraft operate, turnarounds can also be accomplished in approximately one hour. American Airlines' 1974 summer schedule for Flight 59, a Boeing 747 operating from New York to San Francisco for example, arrives at 1212. The aircraft then turns to flight 16 leaving San Francisco at 1315. Turnaround time is thus one hour and three minutes. Similarly TWA's flight 884 operated with L-1011 aircraft arrives at Kennedy from Los Angeles daily at 1653 and returns to Los Angeles as flight 1 departing at 1800 after turnaround time of 1:07. These times are typical of the practices and objectives of most domestic carriers.

Additional factors affecting only international operations were noted earlier. As a result of them, ground handling times for international trips are greater than those for domestic operations. Minimum turn times are typically in the range of 1:30 to 2:30. Variations in station facilities and documentation procedures bear on this figure, however. Review of scheduled times at Braniff's southernmost Latin American stations showed that the 1:30 figure is achieved in Rio de Janeiro on Wednesdays and Buenos Aires on Saturdays. Other turn times range from 1:45 to 9:20 with the higher figures reflecting schedule convenience. Similarly, TWA and Pan American turn around 747 equipment in times in the 1:30 to 2:30 range. Figure 6-1 shows ground times for selected

Figure 6-1

SAMPLE TURNAROUND TIMES - INTERNATIONAL SERVICE
PAN AMERICAN AND TWA
BOEING 747 AIRCRAFT

Carrier	Station	Flight	Arrive	Depart	Ground Time
PA	Barcelona	154	1105		
		155		12:35	1:30
PA	Munich	72	0815		
		73		10:15	2:00
TW	Athens	880	0945		
		881		12:15	2:30
TW	Paris	760[1/]	0830		
		761		10:55	2:25

[1/] Sunday only (arrives Paris 0905) 1:50

Source: Official Airline Guide

flights and stations in Europe. Best time is achieved by Pan American at Barcelona while TWA schedules 2:30 to turn at Athens. The figures indicate the desirability of two hours but show that times can be as little as 1:30 at some stations.

In summary, then, survey data and scheduling information assembled above indicate that wide bodied aircraft operating in passenger service with load factors of 60% or above require transit time at intermediate stops of 50 minutes to one hour in both domestic and international service and minimum turnaround times of 1:30 for international flights. In the scheduling analyses which follow, Speas Associates used a nominal 1:30 ground time as the minimum interval between any consecutive flights.

6.3 Airport Curfews

A potentially important constraint on the scheduling and utilization of long-haul aircraft is the increasing number of international airports where curfews or night restrictions are being imposed. The time-of-day application of curfews varies from one airport to another and sometimes only certain types of aircraft or operations are affected. For example, London's Heathrow airport does not permit takeoffs between 2330 and 0600 local time. Landings are not restricted. Frankfurt restricts night landings but not takeoffs. Tokyo allows neither takeoffs nor landings between 2300 and 0600 local time. Similar curfews are in effect throughout the world.

In view of the increasing concern for the quality of life and the preservation of the environment, this study assumes that by the time they become operational HST aircraft will be required to comply with strict curvews at all of the major airports. (Actually, even in the absence of formal curfews, passenger preferences tend to encourage most airline departures and arrivals to be scheduled during the daytime or evening hours). For consistency in this study, curfew hours of 2330 to 0630 local time have been used at all cities, thus precluding arrivals or departures over this seven-hour period. Consequently, a trip from one city to another may be ruled out for as much as 14 hours of the day. This is essentially the case today for subsonic aircraft flying eastbound across the Atlantic. Afternoon departures are not made because the resulting arrival times would be in the middle of the night in Europe and late night departures would violate the departure city curfew. In this case, two "windows" are available, - one in the morning which provides evening arrivals and an evening departure which flies through the night and arrives in Europe after daybreak. On the other hand, westbound transatlantic flights would be affected for considerably less than 14 hours because the curfews effectively overlap when the aircraft move west at approximately "sun speed."

In the general case, the available times of day for the departure opportunities will be determined by the time zone relationship between the origin and destination cities and by the block time required to make the trip.

Figures 6-2 and 6-3 are representative of the time-of-day impact of curfews on aircraft departure opportunities. These figures show the acceptable departure times for particular city pairs for various aircraft design speeds. Figure 6-2, for example, pertains to flights from New York to London. The area shaded

Figure 6-2

ANALYSIS OF CURFEW EFFECTS ON DEPARTURE TIMES

UNCONSTRAINED CASE

```
FROM NYC, ZONE  -4.0
  TO  LON, ZONE + 1.0

 G.C.D.  2988 N.MI.


                         ACCEPTABLE DEPARTURE TIMES, GMT
DESIGN   BLOCK
 MACH     TIME     0   1   2   3   4   5   6   7   8   9   10  11  12  13  14  15  16  17  18  19  20  21  22  23  24

 0.90     6.19     .   .   .   . DDDDDDDDDDDDDDDDDDDDDDDDDDDDD .   .   .   .   .   . AAAAAAAAAAAAAAAAAAAAAAAAAAAA  .


 2.00     3.18     AAAAAAAAAA  . DDDDDDDDDDDDDDDDDDDDDDDDDDDDD .   .   .   .   .   .   .   .   . AAAAAAAAAAAAAAAAAAA
 2.25     2.91     AAAAAAAAAAA . DDDDDDDDDDDDDDDDDDDDDDDDDDDDD .   .   .   .   .   .   .   .   .  AAAAAAAAAAAAAAAAAA
 2.50     2.70     AAAAAAAAAAAA. DDDDDDDDDDDDDDDDDDDDDDDDDDDDD .   .   .   .   .   .   .   .   .   AAAAAAAAAAAAAAAAA
 2.75     2.52     AAAAAAAAAAAA. DDDDDDDDDDDDDDDDDDDDDDDDDDDDD .   .   .   .   .   .   .   .   .   AAAAAAAAAAAAAAAAA
 3.00     2.38     AAAAAAAAAAAAA DDDDDDDDDDDDDDDDDDDDDDDDDDDDD .   .   .   .   .   .   .   .   .   .AAAAAAAAAAAAAAAA
 3.25     2.25     AAAAAAAAAAAAAADDDDDDDDDDDDDDDDDDDDDDDDDDDDD .   .   .   .   .   .   .   .   .   .AAAAAAAAAAAAAAAA
 3.50     2.15     AAAAAAAAAAAAAADDDDDDDDDDDDDDDDDDDDDDDDDDDDD .   .   .   .   .   .   .   .   .   . AAAAAAAAAAAAAAA
 3.75     2.05     AAAAAAAAAAAAAADDDDDDDDDDDDDDDDDDDDDDDDDDDDD .   .   .   .   .   .   .   .   .   . AAAAAAAAAAAAAAA
 4.00     1.97     AAAAAAAAAAAAAADDDDDDDDDDDDDDDDDDDDDDDDDDDDD .   .   .   .   .   .   .   .   .   .  AAAAAAAAAAAAAA
 4.25     1.90     AAAAAAAAAAAAAADDDDDDDDDDDDDDDDDDDDDDDDDDDDD .   .   .   .   .   .   .   .   .   .  AAAAAAAAAAAAAA
 4.50     1.84     AAAAAAAAAAAAAADDDDDDDDDDDDDDDDDDDDDDDDDDDDD .   .   .   .   .   .   .   .   .   .  AAAAAAAAAAAAAA
 4.75     1.79     AAAAAAAAAAAAAADDDDDDDDDDDDDDDDDDDDDDDDDDDDD .   .   .   .   .   .   .   .   .   .  AAAAAAAAAAAAAA
 5.00     1.73     AAAAAAAAAAAAAADDDDDDDDDDDDDDDDDDDDDDDDDDDDD .   .   .   .   .   .   .   .   .   .   AAAAAAAAAAAAA
 5.25     1.69     AAAAAAAAAAAAAADDDDDDDDDDDDDDDDDDDDDDDDDDDDD .   .   .   .   .   .   .   .   .   .   AAAAAAAAAAAAA
 5.50     1.65     AAAAAAAAAAAAAADDDDDDDDDDDDDDDDDDDDDDDDDDDDD .   .   .   .   .   .   .   .   .   .   AAAAAAAAAAAAA
 5.75     1.61     AAAAAAAAAAAAAADDDDDDDDDDDDDDDDDDDDDDDDDDDDD .   .   .   .   .   .   .   .   .   .   AAAAAAAAAAAAA
 6.00     1.58     AAAAAAAAAAAAAADDDDDDDDDDDDDDDDDDDDDDDDDDDDD .   .   .   .   .   .   .   .   .   .   AAAAAAAAAAAAA
 6.25     1.54     AAAAAAAAAAAAAADDDDDDDDDDDDDDDDDDDDDDDDDDDDD .   .   .   .   .   .   .   .   .   .   AAAAAAAAAAAAA
 6.50     1.51     AAAAAAAAAAAAAADDDDDDDDDDDDDDDDDDDDDDDDDDDDD .   .   .   .   .   .   .   .   .   .   AAAAAAAAAAAAA
 6.75     1.49     AAAAAAAAAAAAAADDDDDDDDDDDDDDDDDDDDDDDDDDDDD .   .   .   .   .   .   .   .   .   .   .AAAAAAAAAAAA
 7.00     1.46     AAAAAAAAAAAAAADDDDDDDDDDDDDDDDDDDDDDDDDDDDD .   .   .   .   .   .   .   .   .   .   .AAAAAAAAAAAA
 7.25     1.44     AAAAAAAAAAAAAADDDDDDDDDDDDDDDDDDDDDDDDDDDDD .   .   .   .   .   .   .   .   .   .   .AAAAAAAAAAAA
 7.50     1.42     AAAAAAAAAAAAAADDDDDDDDDDDDDDDDDDDDDDDDDDDDD .   .   .   .   .   .   .   .   .   .   .AAAAAAAAAAAA
 7.75     1.40     AAAAAAAAAAAAAADDDDDDDDDDDDDDDDDDDDDDDDDDDDD .   .   .   .   .   .   .   .   .   .   .AAAAAAAAAAAA
 8.00     1.38     AAAAAAAAAAAAAADDDDDDDDDDDDDDDDDDDDDDDDDDDDD .   .   .   .   .   .   .   .   .   .   .AAAAAAAAAAAA
```

Figure 6-3

ANALYSIS OF CURFEW EFFECTS ON DEPARTURE TIMES

```
FROM NYC, ZONE  -4.0
 TO  TYO, ZONE + 9.0
                                        UNCONSTRAINED CASE
G.C.D.  5841 N.MI.


                         ACCEPTABLE DEPARTURE TIMES, GMT
DESIGN   BLOCK
 MACH     TIME   0   1   2   3   4   5   6   7   8   9  10  11  12  13  14  15  16  17  18  19  20  21  22  23  24

 0.90    11.65   .   .   .   AADDDDDDDDDDDDDDDDDDDDDDDDDDDDD .   .   .   .   .   .   .   .   .   .   .   .   .   .


 2.00     5.64   .   .   .   . DDDDDDDDDDDDDDDDDDDDDDDDDDDDDAAAAAAAAAAAAAAAAAAAAA.   .   .   .   .   .   .   .   .
 2.25     5.10   .   .   .   . DDDDDDDDDDDDDDDDDDDDDDDDDDDDDAAAAAAAAAAAAAAAAAAAAAAA  .   .   .   .   .   .   .   .
 2.50     4.66   .   .   .   . DDDDDDDDDDDDDDDDDDDDDDDDDDDDDAAAAAAAAAAAAAAAAAAAAAAAAA.   .   .   .   .   .   .   .
 2.75     4.31   .   .   .   . DDDDDDDDDDDDDDDDDDDDDDDDDDDDDAAAAAAAAAAAAAAAAAAAAAAAAAA   .   .   .   .   .   .   .
 3.00     4.01   .   .   .   . DDDDDDDDDDDDDDDDDDDDDDDDDDDDDAAAAAAAAAAAAAAAAAAAAAAAAAAA  .   .   .   .   .   .   .
 3.25     3.76   .   .   .   . DDDDDDDDDDDDDDDDDDDDDDDDDDDDDAAAAAAAAAAAAAAAAAAAAAAAAAAAA .   .   .   .   .   .   .
 3.50     3.55   .   .   .   . DDDDDDDDDDDDDDDDDDDDDDDDDDDDD AAAAAAAAAAAAAAAAAAAAAAAAAAAA.   .   .   .   .   .   .
 3.75     3.36   .   .   .   . DDDDDDDDDDDDDDDDDDDDDDDDDDDDD .AAAAAAAAAAAAAAAAAAAAAAAAAAAA   .   .   .   .   .   .
 4.00     3.20   .   .   .   . DDDDDDDDDDDDDDDDDDDDDDDDDDDDD . AAAAAAAAAAAAAAAAAAAAAAAAAAAA  .   .   .   .   .   .
 4.25     3.06   .   .   .   . DDDDDDDDDDDDDDDDDDDDDDDDDDDDD . AAAAAAAAAAAAAAAAAAAAAAAAAAAA  .   .   .   .   .   .
 4.50     2.93   .   .   .   . DDDDDDDDDDDDDDDDDDDDDDDDDDDDD .  AAAAAAAAAAAAAAAAAAAAAAAAAAAA .   .   .   .   .   .
 4.75     2.82   .   .   .   . DDDDDDDDDDDDDDDDDDDDDDDDDDDDD .  AAAAAAAAAAAAAAAAAAAAAAAAAAAA .   .   .   .   .   .
 5.00     2.72   .   .   .   . DDDDDDDDDDDDDDDDDDDDDDDDDDDDD .   AAAAAAAAAAAAAAAAAAAAAAAAAAAA.   .   .   .   .   .
 5.25     2.62   .   .   .   . DDDDDDDDDDDDDDDDDDDDDDDDDDDDD .   AAAAAAAAAAAAAAAAAAAAAAAAAAAA.   .   .   .   .   .
 5.50     2.54   .   .   .   . DDDDDDDDDDDDDDDDDDDDDDDDDDDDD .   AAAAAAAAAAAAAAAAAAAAAAAAAAAA.   .   .   .   .   .
 5.75     2.46   .   .   .   . DDDDDDDDDDDDDDDDDDDDDDDDDDDDD .   .AAAAAAAAAAAAAAAAAAAAAAAAAAAA   .   .   .   .   .
 6.00     2.39   .   .   .   . DDDDDDDDDDDDDDDDDDDDDDDDDDDDD .   .AAAAAAAAAAAAAAAAAAAAAAAAAAAA   .   .   .   .   .
 6.25     2.33   .   .   .   . DDDDDDDDDDDDDDDDDDDDDDDDDDDDD .   .AAAAAAAAAAAAAAAAAAAAAAAAAAAA   .   .   .   .   .
 6.50     2.27   .   .   .   . DDDDDDDDDDDDDDDDDDDDDDDDDDDDD .   .AAAAAAAAAAAAAAAAAAAAAAAAAAAA   .   .   .   .   .
 6.75     2.21   .   .   .   . DDDDDDDDDDDDDDDDDDDDDDDDDDDDD .   . AAAAAAAAAAAAAAAAAAAAAAAAAAAA  .   .   .   .   .
 7.00     2.16   .   .   .   . DDDDDDDDDDDDDDDDDDDDDDDDDDDDD .   . AAAAAAAAAAAAAAAAAAAAAAAAAAAA  .   .   .   .   .
 7.25     2.12   .   .   .   . DDDDDDDDDDDDDDDDDDDDDDDDDDDDD .   . AAAAAAAAAAAAAAAAAAAAAAAAAAAA  .   .   .   .   .
 7.50     2.07   .   .   .   . DDDDDDDDDDDDDDDDDDDDDDDDDDDDD .   . AAAAAAAAAAAAAAAAAAAAAAAAAAAA  .   .   .   .   .
 7.75     2.03   .   .   .   . DDDDDDDDDDDDDDDDDDDDDDDDDDDDD .   . AAAAAAAAAAAAAAAAAAAAAAAAAAAA  .   .   .   .   .
 8.00     1.99   .   .   .   . DDDDDDDDDDDDDDDDDDDDDDDDDDDDD .   .  AAAAAAAAAAAAAAAAAAAAAAAAAAAA .   .   .   .   .
```

with the letter D indicate the times when flights would be restricted by curfew at the departure city and areas shaded with the letter A apply similarly to the arrival city.

In the New York to London example, the subsonic Mach 0.9 aircraft would be unable to depart between 0330 and 1030 GMT (2330 and 0630 local time) because of the New York curfew and would also be unable to depart between 1630 and 2330 GMT (1230 and 1930 local time in New York) because the arrival would occur during the night curfew at London. Thus, this figure shows the two "departure windows" that are presently used by eastbound transatlantic flights. Proceeding down the chart to increasing vehicle speeds, it will be noted that the evening "window" eventually becomes unavailable whereas the morning "window" widens.

Figure 6-3 shows a similar analysis for flights from New York to Tokyo. In this case, the curfew effects on subsonic aircraft almost exactly overlap. However, aircraft with higher speed capabilities would find an increasingly larger part of the day would be unavailable for departures. At very high speeds a small "window" becomes available for early morning departures from New York which can reach Tokyo just before the night curfew. In practice, however, this would be an unattractive schedule for the airline because the aircraft would be obliged to remain overnight at Tokyo since it would not have enough time to refuel, reload and depart.

Quite clearly, then, the advent of new, faster aircraft will bring about important changes in aircraft scheduling practices because many of the departure times which presently are popular will be unavailable while new departure opportunities will appear.

Nevertheless, it is not immediately clear whether the overall effect will be a reduction or an increase in the potentially available aircraft utilization and productivity.

6.4 Scheduling Analysis

As noted in the Introduction to this chapter, the intent of the present study was to determine whether there were significant scheduling problems inherent in a very fast, long range aircraft which must observe airport curfews, and secondly to determine the extent to which sonic boom constraints would limit the potential aircraft productivity.

(a) Trans Atlantic Routes

One operation of special interest is the North Atlantic service connecting the eastern U.S. with western Europe. The forecast section of this report indicated that this will continue to be the largest single market for long-haul passenger transportation. The city pairs constituting this market include such cities as New York, Boston, Philadelphia, Baltimore and Washington in the U.S. and London, Paris, Amsterdam, Frankfurt, Brussels, Copenhagen and others in Euope. New York-London was selected as the representative individual city pair for the aircraft analysis.

Examination of a large number of scheduling patterns indicated that although five ocean crossings per day could technically be flown by an aircraft flying as slow as Mach 2, the actual operation of such a schedule would be quite improbable. Faster aircraft did not necessarily find better opportunities to make five daily crossings, in fact higher speeds were sometimes a deterrent to higher productivity. For example, an aircraft with a design speed of Mach 3.5 which can make the crossing in 2.15 hours in the unconstrained case might fly the itinerary indicated in Figure 6-4. It will be noted that

Figure 6-4

EXAMPLE FLIGHT ITINERARY
FIVE ATLANTIC CROSSINGS PER DAY

- No Boom Constraints
- Design Speed Mach 3.5
- Block Time 2.15 Hours

			GMT*	Local Time*	
(1)	Dep	NYC	3.35	23.35	
	Arr	LON	5.50	6.50[a]	
					2.85 hr. turn
(2)	Dep	LON	8.35	9.35	
	Arr	NYC	10.50	6.50[a]	
					1.5 hr. turn
(3)	Dep	NYC	12.00	8.00	
	Arr	LON	14.15	15.15	
					1.5 hr. turn
(4)	Dep	LON	15.65	16.65	
	Arr	NYC	17.80	13.80	
					1.5 hr. turn
(5)	Dep	NYC	19.30	15.40	
	Arr	LON	21.45	22.45	

* Times are in decimal hours.

[a] Arrives as curfew ends.

the first crossing leaves New York just before the night closing and arrives at London as it opens in the morning. The departure opportunity is only 0.15 hr. (9 minutes) wide. Later departures would violate the New York curfew and earlier ones would arrive before the London airport opens in the morning. Without this small night "window" however, five crossings would be impossible. Faster aircraft which could make a crossing in less than two hours would be unable to use the night window and could thus make only four crossings per day. Alternatively, a deliberate slow-down could be used on this first crossing to avoid arriving too early. However, this derrogates the potential productivity of the aircraft and would only marginally widen the available "window". Finally, after making the fifth crossing in Figure 6-4 the aircraft is stranded in London for the night and the earliest it could resume flying would be a repetition of the second flight which departs London at 9:35 hours local time, and only four trips could be flown that day.

Thus, it appears most likely that aircraft used exclusively in the transatlantic market would fly a schedule calling for four crossings (two round trips) per day. Figure 6-5 shows possible schedule itineraries for aircraft which would remain overnight at either London or New York. For this particular example the daily operating statistics would be:

Block time (4 @ 2.15)	8.6 hours
Three turnarounds @1.5	4.5 hours
Overnight stay	10.9 hours
	24.0 hours
Miles flown (4 @ 2,988)	11,952 n. mi.
Avg. block speed	1,390 knots

Figure 6-5

EXAMPLE FLIGHT ITINERARIES
FOUR ATLANTIC CROSSINGS PER DAY

- No Boom Constraints
- Design Speed Mach 3.5
- Block Time 2.15 Hours

	Overnight in London				Overnight in New York			
			GMT*	Local*			GMT*	Local*
(1)	Dep	LON	8.35	9.35	Dep	NYC	10.50	6.50
	Arr	NYC	10.50	6.50	Arr	LON	12.65	13.65
				1.5 hr. turn				
(2)	Dep	NYC	12.00	8.00	Dep	LON	14.15	15.15
	Arr	LON	14.15	15.15	Arr	NYC	16.30	12.30
				1.5 hr. turn				
(3)	Dep	LON	15.65	16.65	Dep	NYC	17.80	13.80
	Arr	NYC	17.80	13.80	Arr	LON	19.95	20.95
				1.5 hr. turn				
(4)	Dep	NYC	19.30	15.30	Dep	LON	21.45	22.45
	Arr	LON	21.45	22.45	Arr	NYC	23.60	19.60

* Times are in decimal hours.

With such an operating plan, faster aircraft would not directly offer increased productivity. Their principal advantages would be that they would allow more ground time for maintenance and some added latitude in the choice of scheduled departure times. In the example shown, there is slightly over one hour of "slack" in the schedule, i.e. delays of up to one hour or deliberate scheduling one hour later would not disrupt the schedule pattern. The faster aircraft would also potentially be able to make deeper penetrations to inland cities without losing the capability to make the four daily crossings.

(b) World-Wide Routes

In the more general case, HST aircraft would probably be used on a number of segments of varying stage lengths and with cities in many different time zones.

Because the analysis was to take into account aircraft capable of a broad range of design speeds and operations under three different possible sonic boom constraints and an almost limitless number of possible schedule itineraries, a computer-based model was developed to explore the world-wide scheduling problem. It was found that a reasonably unsophisticated scheduling algorithm could be formulated for this purpose. This algorithm attempts to minimize aircraft ground time (i.e. maximize flight utilization) and provide service to all route segments according to the assignment of passenger demand while abiding by night curfews at every airport in the network.

The first step in the computation process is the determination of the block time for each of the 44 segments (22 city pairs) for the aircraft design Mach number being considered and the type of sonic boom rule being imposed.

The second step is the estimation of the passenger demand. Recalling that the nominal forecast developed in Section 4 of this report is intended to correspond to the block speed capabilities of a Mach 4.0 aircraft flying with the so-called mixed boom restrictions, each of the forecast demand figures was adjusted for the block times of the particular case. The adjustment methodology was in accordance with the time elasticity of demand (the square root relationship) discussed earlier. The demand was expressed in numbers of one-way flights by dividing the passenger demand by 100,000, thus the nominal demand would be about 129 trips on the New York-London segment, 19 between New York and Madrid and so on.

A starting point was then selected. This selection was arbitrary, but for the comparative analyses each itinerary started at New York at a time of zero hours GMT. An itinerary was then constructed proceeding from city to city according to the following algorithm.

<u>Step 1</u> If the aircraft is otherwise ready to depart but the night curfew is in effect at its present location, departure must be delayed until the end of the curfew period (0630 hours local time). Proceed to step 2.

<u>Step 2</u> Having determined that a departure would now be allowed, a search is made for all the possible destinations which have some demand unsatisfied and where curfews would allow the

arrival, turnaround and a subsequent departure with no delay. If there is only one such destination available the aircraft makes that trip and is ready to repeat step 2. If there are two or more possible destinations, the aircraft will fly the segment with the greatest percentage of its demand unsatisfied. If there are no destinations that would allow an immediate arrival, turnaround and departure, proceed to step 3.

Step 3 A search is made for all the possible destinations with some unsatisfied demand where curfews would allow an arrival but not necessarily an undelayed turnaround and departure. If there is only one such destination the aircraft makes that trip and returns to step 1. Again, if there are two or more possible destinations the selection is made on the basis of greatest percentage of demand unsatisfied. If there are no destinations available, proceed to step 4.

Step 4 This step in the algorithm will be reached whenever delay is inevitable because of inability to find a satisfactory destination in step 2 or step 3. This implies that all of the destinations with some unsatisfied demand would be closed by their respective curfews at the projected arrival times. In this event, the destination selected is the one which will open at such a time as to allow the least pre-departure delay. Accept this delay then return to step 1.

In summary, then, this algorithm "looks ahead" for no more than one and one-half moves (the half move being the turnaround time after a trip). If it can find moves that will incur no delays, it makes a selection based on the level of unsatisfied demand. If delay is inevitable it chooses the move with the least delay provided there is still some unsatisfied demand for that move. The computation is terminated when the elapsed time for the itinerary reaches 500 hours (about 21 days).

Figure 6-6 shows the itinerary that this algorithm determined for the mixed sonic boom constraint case for a Mach 5 aircraft. The aircraft starts at New York at zero hours GMT and goes to Caracas with no delay, arriving after an elapsed time of 1.55 hours. It would be ready to depart Caracas after 1.5 hours (3.05 hours total elapsed time), but of the two possible destinations, New York and Madrid, only Madrid would be open at the projected arrival time. Thus the aircraft goes to Madrid, then to Rio, back to Madrid, to Caracas and then to New York after a total elapsed time of 21.56 hours or almost one day. Except for the required 1.5 hour turnaround time between flights, no delays were necessary. The first delay occurs at the end of the second day when a night departure from Chicago to London must wait 0.35 hours (21 minutes) to ensure that London will be open on arrival. While this delay is minimal, it does reveal a shortcoming of a scheduling algorithm that does not look sufficiently far ahead. In this case, Chicago is associated with only one other city (London), and if delays are to be avoided the LON-CHI segment should not be flown without ensuring that the return CHI-LON will be possible. A human scheduler or a more sophisticated computer

Figure 6-6, Part 1

R. DIXON SPEAS ASSOCIATES
HST SCHEDULING ANALYSIS

RUN AT MACH 5.00
MIXED BOOM CONSTRAINTS

ELAPSED TIME HR	DEPART			ARRIVE			DELAY HOURS		BLOCK HOURS		A/C MILES	
		GMT	LOCAL		GMT	LOCAL	TRIP	CUM	TRIP	CUM	TRIP	CUM
1.55	NYC	-0.0	20.00	CCS	1.55	21.55	0.0	0.0	1.55	1.5	1837	1837
5.69	CCS	3.05	23.05	MAD	5.69	6.69	0.0	0.0	2.64	4.2	3779	5616
10.03	MAD	7.19	8.19	RIO	10.03	7.03	0.0	0.0	2.84	7.0	4394	10010
14.37	RIO	11.53	8.53	MAD	14.37	15.37	0.0	0.0	2.84	9.9	4394	14404
18.51	MAD	15.87	16.87	CCS	18.51	14.51	0.0	0.0	2.64	12.5	3779	18183
21.56	CCS	20.01	16.01	NYC	21.56	17.56	0.0	0.0	1.55	14.1	1837	20020
25.53	NYC	23.06	19.06	HNL	1.53	15.53	0.0	0.0	2.47	16.5	4303	24323
28.70	HNL	3.03	17.03	LAX	4.70	21.70	0.0	0.0	1.67	18.2	2200	26523
31.87	LAX	6.20	23.20	HNL	7.87	21.87	0.0	0.0	1.67	19.9	2200	28723
35.84	HNL	9.37	23.37	NYC	11.84	7.84	0.0	0.0	2.47	22.3	4303	33026
39.26	NYC	13.34	9.34	LAX	15.26	8.26	0.0	0.0	1.92	24.3	2143	35169
43.55	LAX	16.76	9.76	LON	19.55	20.55	0.0	0.0	2.79	27.0	4725	39894
48.35	LON	21.05	22.05	CHI	0.35	19.35	0.0	0.0	3.30	30.3	3421	43315
53.50	CHI	2.20	21.20	LON	5.50	6.50	0.35	0.35	3.30	33.6	3421	46736
58.53	LON	7.00	8.00	SIN	10.53	18.03	0.0	0.35	3.53	37.2	5866	52602
63.52	SIN	12.03	19.53	LAX	15.52	8.52	0.0	0.35	3.49	40.7	7609	60211
66.94	LAX	17.02	10.02	NYC	18.94	14.94	0.0	0.35	1.92	42.6	2143	62354
70.96	NYC	20.44	16.44	RIO	22.96	19.96	0.0	0.35	2.52	45.1	4169	66523
74.98	RIO	0.46	21.46	NYC	2.98	22.98	0.0	0.35	2.52	47.6	4169	70692
84.59	NYC	10.50	6.50	LON	12.59	13.59	6.02	6.37	2.09	49.7	2988	73680
88.88	LON	14.09	15.09	LAX	16.88	9.88	0.0	6.37	2.79	52.5	4725	78405
92.30	LAX	18.38	11.38	NYC	20.30	16.30	0.0	6.37	1.92	54.4	2143	80548
96.84	NYC	21.80	17.80	TYO	0.84	9.84	0.0	6.37	3.04	57.5	5841	86389
100.47	TYO	2.34	11.34	HNL	4.47	18.47	0.0	6.37	2.13	59.6	3325	89714
104.26	HNL	5.97	19.97	SYD	8.26	18.26	0.0	6.37	2.29	61.9	4419	94133
109.93	SYD	9.76	19.76	LON	13.93	14.93	0.0	6.37	4.17	66.1	9178	103311
113.80	LON	15.43	16.43	MIA	17.80	13.80	0.0	6.37	2.37	68.4	3834	107145
117.67	MIA	19.30	15.30	LON	21.67	22.67	0.0	6.37	2.37	70.8	3834	110979
129.67	LON	5.50	6.50	SYD	9.67	19.67	6.33	12.70	4.17	75.0	9178	120157
133.39	SYD	11.17	21.17	SIN	13.39	20.89	0.0	12.70	2.22	77.2	3397	123554
138.42	SIN	14.89	22.39	LON	18.42	19.42	0.0	12.70	3.53	80.7	5866	129420
142.01	LON	19.92	20.92	NYC	22.01	18.01	0.0	12.70	2.09	82.8	2988	132408
145.43	NYC	23.51	19.51	LAX	1.43	18.43	0.0	12.70	1.92	84.7	2143	134551
150.42	LAX	2.93	19.93	SIN	6.42	13.92	0.0	12.70	3.49	88.2	7609	142160
154.14	SIN	7.92	15.42	SYD	10.14	20.14	0.0	12.70	2.22	90.4	3397	145557

Figure 6-6, Part 2

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                                         R. DIXON SPEAS ASSOCIATES
                                          HST SCHEDULING ANALYSIS
 RUN AT MACH 5.00
MIXED BOOM CONSTRAINTS

             DEPART                 ARRIVE                 DELAY HOURS      BLOCK HOURS       A/C MILES
ELAPSED
TIME HR           GMT  LOCAL             GMT  LOCAL     TRIP     CUM     TRIP      CUM     TRIP     CUM

 159.81      SYD 11.64 21.64     LON 15.81 16.81     0.0     12.70     4.17      94.6   9178  154735
 163.40      LON 17.31 13.31     NYC 19.40 15.40     0.0     12.70     2.09      96.7   2988  157723
 166.82      NYC 20.90 16.90     LAX 22.82 15.82     0.0     12.70     1.92      98.6   2143  159866
 170.86      LAX  0.32 17.32     TYO  2.86 11.86     0.0     12.70     2.54     101.2   4712  164578
 175.26      TYO  4.36 13.36     LON  7.26  8.26     0.0     12.70     2.90     104.1   5173  169751
 179.66      LON  8.76  9.76     TYO 11.66 20.66     0.0     12.70     2.90     107.0   5173  174924
 183.70      TYO 13.16 22.16     LAX 15.70  8.70     0.0     12.70     2.54     109.5   4712  179636
 187.12      LAX 17.20 10.20     NYC 19.12 15.12     0.0     12.70     1.92     111.4   2143  181779
 190.54      NYC 20.62 16.62     LAX 22.54 15.54     0.0     12.70     1.92     113.3   2143  183922
 193.71      LAX  0.04 17.04     HNL  1.71 15.71     0.0     12.70     1.67     115.0   2200  186122
 197.34      HNL  3.21 17.21     TYO  5.34 14.34     0.0     12.70     2.13     117.1   3325  189447
 201.74      TYO  6.84 15.84     LON  9.74 10.74     0.0     12.70     2.90     120.0   5173  194620
 206.54      LON 11.24 12.24     CHI 14.54  9.54     0.0     12.70     3.30     123.3   3421  198041
 211.34      CHI 16.04 11.04     LON 19.34 20.34     0.0     12.70     3.30     126.6   3421  201462
 214.93      LON 20.84 21.84     NYC 22.93 18.93     0.0     12.70     2.09     128.7   2988  204450
 218.35      NYC  0.43 20.43     LAX  2.35 19.35     0.0     12.70     1.92     130.6   2143  206593
 222.64      LAX  3.85 20.85     LON  6.64  7.64     0.0     12.70     2.79     133.4   4725  211318
 227.67      LON  8.14  9.14     SIN 11.67 19.17     0.0     12.70     3.53     137.0   5866  217184
 232.70      SIN 13.17 20.67     LON 16.70 17.70     0.0     12.70     3.53     140.5   5866  223050
 236.29      LON 18.20 19.20     NYC 20.29 16.29     0.0     12.70     2.09     142.6   2988  226038
 239.71      NYC 21.79 17.79     LAX 23.71 16.71     0.0     12.70     1.92     144.5   2143  228181
 243.75      LAX  1.21 18.21     TYO  3.75 12.75     0.0     12.70     2.54     147.0   4712  232893
 247.38      TYO  5.25 14.25     HNL  7.38 21.38     0.0     12.70     2.13     149.2   3325  236218
 251.01      HNL  8.88 22.88     TYO 11.01 20.01     0.0     12.70     2.13     151.3   3325  239543
 255.55      TYO 12.51 21.51     NYC 15.55 11.55     0.0     12.70     3.04     154.3   5841  245384
 259.30      NYC 17.05 13.05     MAD 19.30 20.30     0.0     12.70     2.25     156.6   3109  248493
 263.05      MAD 20.80 21.80     NYC 23.05 19.05     0.0     12.70     2.25     158.8   3109  251602
 266.47      NYC  0.55 20.55     LAX  2.47 19.47     0.0     12.70     1.92     160.8   2143  253745
 270.76      LAX  3.97 20.97     LON  6.76  7.76     0.0     12.70     2.79     163.6   4725  258470
 275.56      LON  8.26  9.26     CHI 11.56  6.56     0.0     12.70     3.30     166.9   3421  261891
 280.36      CHI 13.06  8.06     LON 16.36 17.36     0.0     12.70     3.30     170.2   3421  265312
 283.95      LON 17.86 18.86     NYC 19.95 15.95     0.0     12.70     2.09     172.2   2988  268300
 287.00      NYC 21.45 17.45     CCS 23.00 19.00     0.0     12.70     1.55     173.8   1837  270137
 290.05      CCS  0.50 20.50     NYC  2.05 22.05     0.0     12.70     1.55     175.3   1837  271974
 300.67      NYC 10.50  6.50     ROM 12.67 13.67     6.95    19.65     2.17     177.5   3703  275677
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Figure 6-6, Part 3

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                                R. DIXON SPEAS ASSOCIATES
                                 HST SCHEDULING ANALYSIS
 RUN AT MACH 5.00
MIXED BOOM CONSTRAINTS

              DEPART                 ARRIVE                DELAY HOURS      BLOCK HOURS       A/C MILES
ELAPSED
TIME HR           GMT  LOCAL            GMT  LOCAL     TRIP     CUM      TRIP      CUM     TRIP     CUM

 304.34     ROM 14.17 15.17      NYC 16.34 12.34      0.0     19.65     2.17     179.7    3703   279380
 307.93     NYC 17.84 13.84      LON 19.93 20.93      0.0     19.65     2.09     181.8    2988   282368
 312.22     LON 21.43 22.43      LAX  0.22 17.22      0.0     19.65     2.79     184.6    4725   287093
 315.39     LAX  1.72 18.72      HNL  3.39 17.39      0.0     19.65     1.67     186.2    2200   289293
 319.02     HNL  4.89 18.89      TYO  7.02 16.02      0.0     19.65     2.13     188.4    3325   292618
 323.42     TYO  8.52 17.52      LON 11.42 12.42      0.0     19.65     2.90     191.3    5173   297791
 327.01     LON 12.92 13.92      NYC 15.01 11.01      0.0     19.65     2.09     193.4    2988   300779
 330.60     NYC 16.51 12.51      LON 18.60 19.60      0.0     19.65     2.09     195.4    2988   303767
 335.40     LON 20.10 21.10      CHI 23.40 18.40      0.0     19.65     3.30     198.7    3421   307188
 341.50     CHI  2.20 21.20      LON  5.50  6.50      1.30    20.95     3.30     202.0    3421   310609
 345.90     LON  7.00  8.00      TYO  9.90 18.90      0.0     20.95     2.90     204.9    5173   315782
 349.94     TYO 11.40 20.40      LAX 13.94  6.94      0.0     20.95     2.54     207.5    4712   320494
 353.36     LAX 15.44  8.44      NYC 17.36 13.36      0.0     20.95     1.92     209.4    2143   322637
 356.95     NYC 18.86 14.86      LON 20.95 21.95      0.0     20.95     2.09     211.5    2988   325625
 360.54     LON 22.45 23.45      NYC  0.54 20.54      0.0     20.95     2.09     213.6    2988   328613
 363.96     NYC  2.04 22.04      LAX  3.96 20.96      0.0     20.95     1.92     215.5    2143   330756
 368.25     LAX  5.46 22.46      LON  8.25  9.25      0.0     20.95     2.79     218.3    4725   335481
 372.12     LON  9.75 10.75      MIA 12.12  8.12      0.0     20.95     2.37     220.7    3834   339315
 375.99     MIA 13.62  9.62      LON 15.99 16.99      0.0     20.95     2.37     223.0    3834   343149
 379.58     LON 17.49 18.49      NYC 19.58 15.58      0.0     20.95     2.09     225.1    2988   346137
 383.55     NYC 21.08 17.08      HNL 23.55 13.55      0.0     20.95     2.47     227.6    4303   350440
 386.72     HNL  1.05 15.05      LAX  2.72 19.72      0.0     20.95     1.67     229.3    2200   352640
 389.89     LAX  4.22 21.22      HNL  5.89 19.89      0.0     20.95     1.67     230.9    2200   354840
 393.68     HNL  7.39 21.39      SYD  9.68 19.68      0.0     20.95     2.29     233.2    4419   359259
 397.40     SYD 11.18 21.18      SIN 13.40 20.90      0.0     20.95     2.22     235.4    3397   362656
 402.43     SIN 14.90 22.40      LON 18.43 19.43      0.0     20.95     3.53     239.0    5866   368522
 407.23     LON 19.93 20.93      CHI 23.23 18.23      0.0     20.95     3.30     242.3    3421   371943
 413.50     CHI  2.20 21.20      LON  5.50  6.50      1.47    22.43     3.30     245.6    3421   375364
 416.53     LON  7.00  8.00      SIN 10.53 18.03      0.0     22.43     3.53     249.1    5866   381230
 423.52     SIN 12.03 19.53      LAX 15.52  8.52      0.0     22.43     3.49     252.6    7609   388839
 426.94     LAX 17.02 10.02      NYC 18.94 14.94      0.0     22.43     1.92     254.5    2143   390982
 430.36     NYC 20.44 16.44      LAX 22.36 15.36      0.0     22.43     1.92     256.4    2143   393125
 433.78     LAX 23.86 16.86      NYC  1.78 21.78      0.0     22.43     1.92     258.4    2143   395268
 437.53     NYC  3.28 23.28      MAD  5.53  6.53      0.0     22.43     2.25     260.6    3109   398377
 441.87     MAD  7.03  8.03      RIO  9.87  6.87      0.0     22.43     2.84     263.4    4394   402771
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Figure 6-6, Part 4

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                                           R. DIXON SPEAS ASSOCIATES
                                            HST SCHEDULING ANALYSIS
 RUN AT MACH 5.00
MIXED BOOM CONSTRAINTS

              DEPART                ARRIVE                DELAY HOURS     BLOCK HOURS        A/C MILES
ELAPSED
TIME HR            GMT  LOCAL            GMT  LOCAL       TRIP     CUM      TRIP      CUM    TRIP    CUM

 445.89       RIO 11.37   8.37      NYC 13.89   9.89      0.0    22.43     2.52     266.0   4169   406940
 449.48       NYC 15.39  11.39      LON 17.48  18.48      0.0    22.43     2.09     268.1   2988   409928
 453.07       LON 18.98  19.98      NYC 21.07  17.07      0.0    22.43     2.09     270.1   2988   412916
 456.49       NYC 22.57  18.57      LAX  0.49  17.49      0.0    22.43     1.92     272.1   2143   415059
 460.53       LAX  1.99  18.99      TYO  4.53  13.53      0.0    22.43     2.54     274.6   4712   419771
 464.93       TYO  6.03  15.03      LON  8.93   9.93      0.0    22.43     2.90     277.5   5173   424944
 468.52       LON 10.43  11.43      NYC 12.52   8.52      0.0    22.43     2.09     279.6   2988   427932
 472.19       NYC 14.02  10.02      ROM 16.19  17.19      0.0    22.43     2.17     281.8   3703   431635
 475.86       ROM 17.69  13.69      NYC 19.86  15.86      0.0    22.43     2.17     283.9   3703   435338
 479.28       NYC 21.36  17.36      LAX 23.28  16.28      0.0    22.43     1.92     285.9   2143   437481
 484.27       LAX  0.78  17.78      SIN  4.27  11.77      0.0    22.43     3.49     289.3   7609   445090
 489.30       SIN  5.77  13.27      LON  9.30  10.30      0.0    22.43     3.53     292.9   5866   450956
 493.59       LON 10.80  11.80      LAX 13.59   6.59      0.0    22.43     2.79     295.7   4725   455681
 497.01       LAX 15.09   8.09      NYC 17.01  13.01      0.0    22.43     1.92     297.6   2143   457824
 500.60       NYC 18.51  14.51      LON 20.60  21.60      0.0    22.43     2.09     299.7   2988   460812
```

technique could easily avoid such delays.

Inspection of the schedules produced in this way showed that essentially all delays could have been avoided by "looking ahead" only two or three moves. Thus it appears that itineraries of an indefinite number of segments could be assembled which would be responsive to the relative levels of demand on all segments and which could be flown without unwanted delays. However, in actual practice a schedule should include substantially more "delay" than that resulting from the simple model. A real schedule would deliberately impose occasional delays beyond the minimum turnaround time to ensure good connections with other aircraft and would also establish periods of "downtime" for maintenance each day.

A principal conclusion that may be drawn from this analysis is that even though the scheduling techniques used were considerably less sophisticated than those which might be put into actual practice, airport curfews were not found to be great obstacles to productive utilization of high speed aircraft. This is so because such aircraft are likely to be used on long-haul, world-wide route networks which span many time zones. Unlike the route network of a short-haul regional carrier where night curfews would close all of the system at the same time, a worldwide network always has a large number of airports open for operation and there are always adequate opportunities to provide non-stop service connecting any pair of cities.

6.5 Aircraft Productivity

Figure 6-7 is a summary of the operating statistics for each aircraft design Mach number and each of the three sonic boom

Figure 6-7

SUMMARY OF HST OPERATING STATISTICS
WORLD-WIDE SCHEDULING ANALYSIS

Design Speed (M) (1)	Elapsed Time (hr) (2)	Total Delay (hr) (3)	Block Time (hr) (4)	N. Miles Flown (000) (5)	Segments Flown (6)	Block Speed (knots) (7)	N. Miles Per Elapsed Hour (8)
A. No Sonic Boom Constraints							
.9	501.3	12.0	415.7	204.9	50	493	409
2	500.6	5.1	359.0	352.0	92	981	703
3	500.4	29.9	308.6	412.3	109	1,336	824
4	500.7	33.0	284.7	464.8	123	1,633	928
5	500.9	52.9	260.6	498.7	126	1,914	996
6	501.0	41.9	253.6	538.6	138	2,124	1,075
7	501.7	32.1	247.6	566.6	149	2,288	1,129
8	500.8	28.6	242.7	601.1	154	2,477	1,200
B. Mixed Sonic Boom Constraints							
.9	501.3	12.0	415.7	204.9	50	493	409
2	500.9	1.4	372.0	333.8	86	897	666
3	502.3	30.5	324.8	379.1	99	1,167	755
4	501.2	30.5	305.7	421.7	111	1,379	841
5	500.6	22.4	299.7	460.8	120	1,538	920
6	502.3	20.8	292.5	486.9	127	1,665	969
7	502.4	13.2	291.2	515.5	133	1,770	1,026
8	502.9	50.3	266.5	485.4	125	1,821	965
C. Strict Sonic Boom Constraints							
.9	501.3	12.0	415.7	204.9	50	493	409
2	505.2	6.2	383.4	293.8	78	766	582
3	505.5	13.7	361.3	329.5	88	912	652
4	501.8	34.1	338.7	338.4	87	999	674
5	500.0	45.1	324.4	362.5	88	1,117	725
6	500.9	24.2	331.3	397.7	98	1,200	794
7	505.1	31.9	323.2	397.0	101	1,228	786
8	505.0	32.3	319.7	417.6	103	1,306	827

Source: Speas Associates Analysis

constraints for the flight itineraries made by the simple scheduling model. In every case the analysis terminates after the total elapsed time exceeds 500 hours. In that time the subsonic aircraft completed 50 flight segments, accounting for some 204,900 aircraft miles flown. The faster aircraft can perform increasingly more trips and miles within the 500 hours.

One measure of aircraft productivity is its average overall block speed, i.e. the miles flown per block hour. This appears in column 7 of Figure 6-7 and is shown plotted against vehicle design Mach number in Figure 6-8. The block speed increases steadily with design speed, although it does not increase in direct proportion with the design speed. This is because the time spent in taxiing, maneuvering, accelerating and decelerating becomes of increasingly greater importance for faster aircraft. For example, without sonic boom limitations, even though a Mach 8 aircraft cruises at twice the speed of a Mach 4 aircraft its block speed is only about 50% greater.

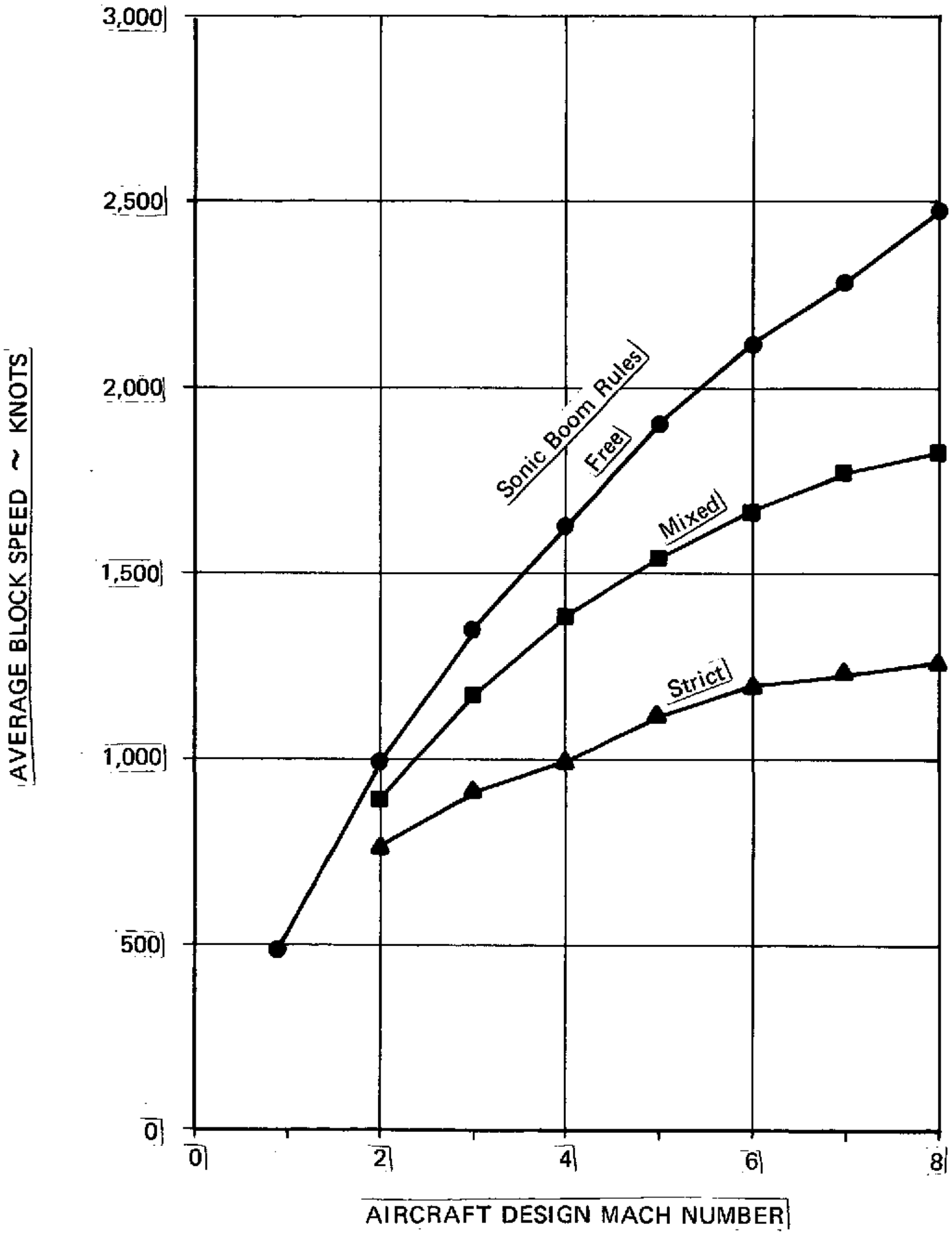
Figure 6-8 shows quite clearly the productivity potential that is lost if sonic boom constraints are imposed. Taking, for example, the Mach 6 aircraft, the block speeds under the three constraint conditions would be:

unconstrained	2,124 knots	
mixed constraint	1,665 knots	(22% loss)
strict constraint	1,200 knots	(44% loss)

Viewed another way, Figure 6-8 shows that if a Mach 2.5 aircraft could be developed which could operate free of sonic boom restrictions it would be as productive (in terms of

Figure 6-8

AIRCRAFT BLOCK SPEED CAPABILITIES
World-Wide Route Systems



Source: Speas Associates Analysis.

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block speed) as a Mach 7 or 8 aircraft that had to abide by strict overwater boom rules.

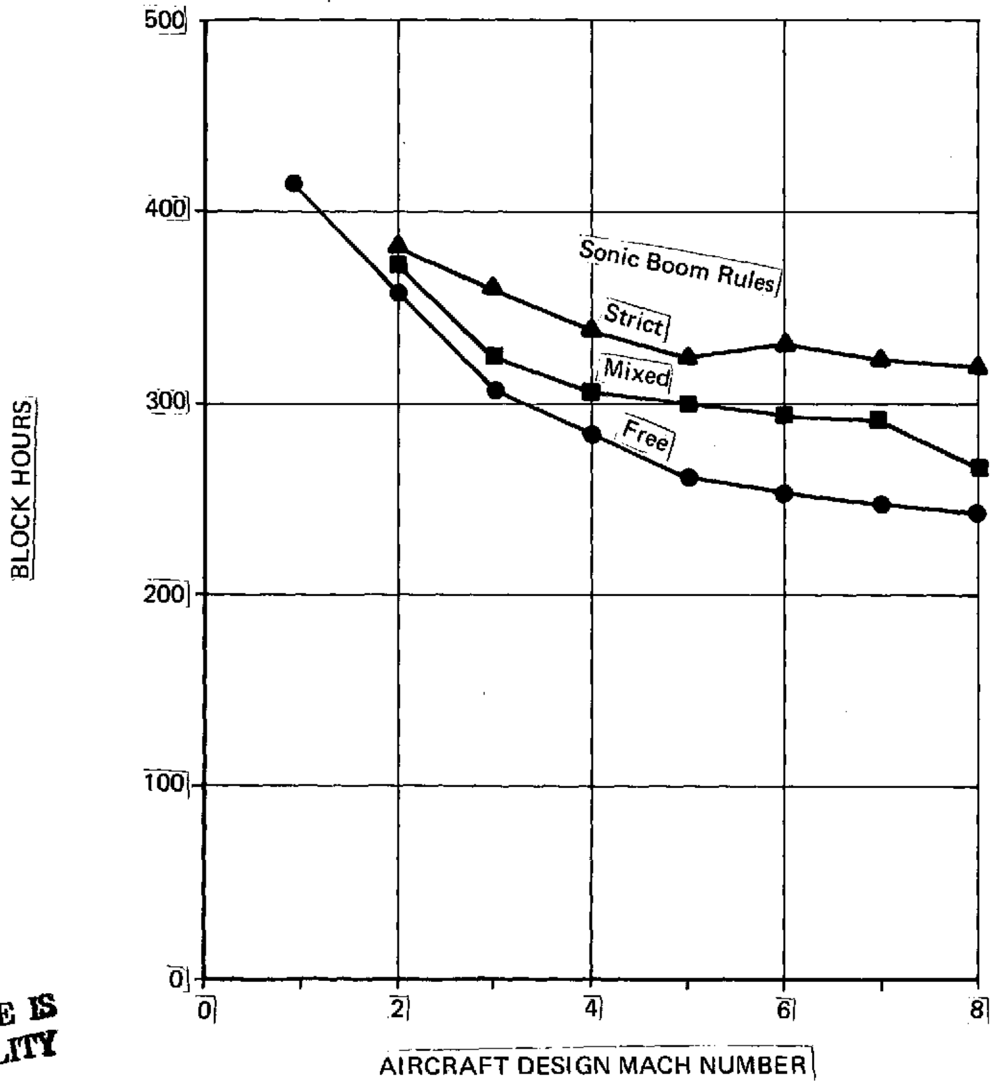
One of the shortcomings in using block speed as an indicator of productivity is that it invites comparisons that assume equal amounts of block time. In actual operations aircraft which make many flights of short duration cannot provide as many block hours in some period of time as aircraft making fewer flights of long duration. This is simply a manifestation of the ground time required between each flight. The decline in available block time with increasing vehicle speed (i.e. decreasing average flight duration) is borne out by the scheduling analysis. Column 4 of Figure 6-7 shows the block time for each of the cases examined. The subsonic aircraft is able to provide 415.7 hours of block time in 501.3 hours of elapsed time, whereas the fastest HST aircraft can provide only about 250 to 350 hours. This is illustrated in Figure 6-9. Thus, even though the faster aircraft have the ability to yield substantial improvements in block speed, this is partially offset by an associated decrease in the available block time.

Possibly a better measure of aircraft productivity potential is the number of seat miles or aircraft miles that could be provided in a given amount of elapsed time. (This was alluded to in the earlier discussion of aircraft confined to transatlantic operations where the probable limit of practical utilization would be four crossings per day regardless of increasing flight speed or block speed). In the case of the world-wide route system the figure of merit would be the average number of miles flown in the approximately 500 hours of "duty time". In this context duty time includes all block time, turnaround time and delay time but not maintenance down-time. In real operations there would be some 200 to 300

Figure 6-9

BLOCK HOURS FLOWN AFTER 500 HOURS ELAPSED TIME

World-Wide Route Systems



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Source: Speas Associates Analysis.

additional hours of down-time for scheduled and unscheduled maintenance in the course of the 500 hours of duty time, but the appropriate measure for the purposes of this report would be the number of aircraft miles per hour of "duty time". This is shown in column 8 of Figure 6-7 and is plotted in Figure 6-10.

As was the case for block speeds, the miles per duty hour tend to increase with increasing design speed but again the increase is not in direct proportion to the design speed. The drop in productivity for the mixed constraint case comparing Mach 8 with Mach 7 is partly due to increased delays encountered by the Mach 8 aircraft and partly due to the circumstances on the New York-Rome flight track selection where a Mach 7 aircraft could decelerate over the Mediterranean whereas a Mach 8 aircraft had to decelerate over the Atlantic, thereby incurring a significant time penalty (see section 5.3, item 20).

Somewhat similar conclusions may be drawn from this productivity index as those shown previously. The impact of the sonic boom constraints on productivity for a Mach 6 aircraft are:

unconstrained	1,075 aircraft miles per duty hour	
mixed constraint	969 aircraft miles per duty hour	(10% loss)
strict constraint	794 aircraft miles per duty hour	(26% loss)

And again, if a Mach 2.5 aircraft could operate without boom restrictions it could be as productive as a Mach 7 or 8 aircraft which was restricted.

Taking the subsonic aircraft as having a productivity of one unit, the relative productivities of the other aircraft/

constraint combinations are as follows.

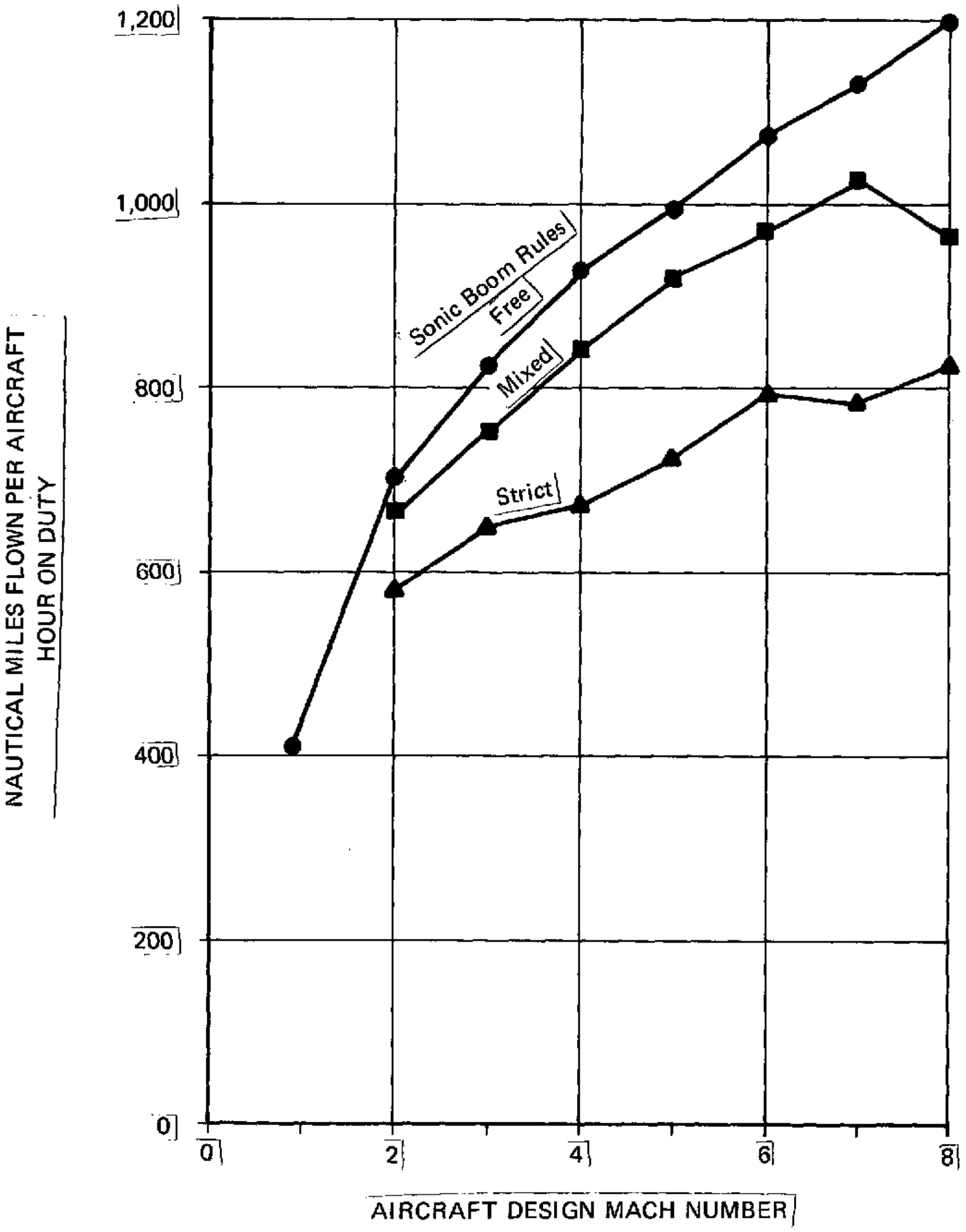
RELATIVE AIRCRAFT PRODUCTIVITIES

Design Mach	Sonic Boom Constraints		
	Free	Mixed	Strict
.9	1.00 (ref)	-	-
2	1.72	1.63	1.42
3	2.01	1.85	1.59
4	2.27	2.06	1.65
5	2.44	2.25	1.77
6	2.63	2.37	1.94
7	2.76	2.51	1.92
8	2.93	2.34	2.02

Figure 6-10

AIRCRAFT PRODUCTIVITY ANALYSIS

Miles Flown per Hour on Duty
World-Wide Route Systems



Source: Speas Associates Analysis.

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