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Operational Requirements For Flight Control and Navigation Systems for Short Haul Transport Aircraft

(NASA-CR-137975) OPERATIONAL REQUIREMENTS FOR FLIGHT CONTROL AND NAVIGATION SYSTEMS FOR SHORT HAUL TRANSPORT AIRCRAFT (AVCON Aviation Consultants, Inc.) 142 p HC A07/MF A01 CSCL 01C G3/05 N77-17034 Unclas 14978

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SUMMARY

The evaluation of operational procedures for use in an assumed short haul transport route indicates operational suitability.

The curved path approaches in airline use by large jet airplanes were studied. The characteristics of these approaches were included in development of operational procedures for transitions and approaches by a jet STOL transport. These procedures were used in a simulation experiment and were satisfactory for autoflight operation. A minimum turn radius of 3,000 ft. for a 180° final turn was determined for the wind conditons tested. The accuracy of the approaches was very good.

The experiment should be extended to manual flight using a flight director.

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LIST OF ABBREVIATIONS USED

ATC	Air Traffic Control
ATZ	Above Touchdown Zone
CG	Center of Gravity
c. p. s.	Cycles per second
CTOL	Conventional Take-off and Landing
3D	Three-dimensional
EAS	Equivalent airspeed
FAA	Federal Aviation Administration
Fm	From
g	1 gravity
G/S	Ground Speed
HOR/NAV	Horizontal Navigation
IAS	Indicated Air Speed
IFR	Instrument Flight Rules
ILS	Instrument Landing System
Kts	Knots
MODILS	Modular Instrument Landing System
MLS	Microwave Landing System
NASA	National Aeronautics & Space Administration
N. M.	Nautical Mile

RFP	Reference Flight Path
RNAV	Area Navigation System
RPM	Revolutions Per Minute
STOLAND	Short take-off and Landing
VFR	Visual Flight Rules
Vs	Versus
Wpt	Waypoint

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INTRODUCTION

People travel by air because it's faster! Yet many travelers find that the advantage of flight is often short curcuited on short hauls by the time and hassle involved in getting to and from most airports. A typical commuter from Boston to Manhattan, for example, must plan on a minimum of five and a half hours to make that trip on current conventional commuter surface and air carriers. Even if the airplane utilized were able or allowed to fly at 1,000 miles per hour, the trip would still take five hours from downtown to downtown.

Within the constraints of current airports and airplanes, the airlines have made extensive efforts to ease the problem. In several high density travel areas they are operating conventional airplanes in a "commuter" service. Attempts to shorten the passenger's travel time have been largely confined to carry-on baggage facilities, onboard ticketing, and hourly departures. The airplane still has to use a Conventional Take-off and Landing (CTOL) runway at origin and destination, and fit into the regular flow of traffic between the two. These efforts have no doubt made commuter travel more efficient and attractive but because of airport locations, they have done little to reduce travel time. A basic ingredient in this problem is that airports must be located far from downtown centers because of land costs, noise, and the need for plenty of unobstructed space for CTOL airplanes.

To ease the traveler's burden, improve air transportation systems, and lay groundwork for better commercial exploitation of a major commuter market,

NASA is researching advanced technology airplanes especially designed for Short Take-off and Landing (STOL) to be used on a future generation of small, close-in airfields, which will give the short-haul commuter airlines something very close to "downtown to downtown" service. For example, the STOL route for the Boston to Manhattan commuter run referenced above could very possibly be shortened to as little as two hours downtown to downtown.

Several STOL airplanes are presently under development at this time, including De Havilland's D-7, Boeing's YC-14 and McDonnell Douglas' YC-15. These airplanes will become operational in U. S. air traffic in the near future. Today - the U. S. air traffic system is rapidly becoming traffic saturated. The area navigation (RNAV) concept will also become operational in our air traffic system in the near future. The purpose of this study is to identify, evaluate and refine operational procedures for flying transistions from enroute RNAV paths to time constrained approaches and landings of jet powered STOL transport type airplanes.

STOL airplane flight operations generally employ steeper approaches and take-offs at lower speeds than CTOL operations, and may involve the use of an approach and landing pattern where the airplane makes a descending turn just before touchdown. The advantage of both these maneuvers is that the area affected by landing patterns is so much smaller than CTOL operations. This translates into less noise and fewer congestion problems. The length of the runway can be shortened considerably and the airport can be moved closer to town.

This study is limited to the approach and landing part of the STOL com-

muter route because of limitations of the Augmentor Wing Simulation. The curved paths examined are from an assumed short haul route between Boston and Manhattan.

BACKGROUND

Operational requirements for flight control and navigation systems for short haul transport aircraft will be dictated to a large degree by the operational environment required by the user. Users in this context include three groups which are deeply concerned with the concept and should be entitled to make an input to the operational requirements: The passenger; the pilot; and airline operational management. An attempt has been made in this study to address some of the requirements of each of these groups.

The airline passenger should be given prime consideration as he ultimately creates the need for the entire system. His need or desire to get from point A to point B is the basis upon which the system will eventually stand. His basic requirements include safety, timeliness and comfort. The passenger always expects to depart and arrive without undue hazard to life and limb. As safety is not a basic topic for this study, operational safety of the short haul transport system is assumed to be at least as good as that for conventional air transportation systems today.

The short-haul transport system must attain a high degree of reliability with adequate redundancy to insure consistent operations so the passenger will hold high regard for a printed flight schedule. This requirement will be addressed by systems manufacturers. Satisfactory reliability of the systems is assumed here.

STOL operations will involve steeper departures and arrivals than the CTOL passenger is used to. This might pose a passenger comfort problem,

therefore, can procedures be established such that the passenger will enjoy his STOL flight as much as he does current CTOL flights, or will he feel like he has to hang onto his seat during the entire flight?

The airline pilot is interested in all of the passenger aspects of air transportation plus his own workload. Inasmuch as he will perform his duties routinely day and night, good weather or bad, the pilot skills required will have to be no more demanding than those presently required in airline operations. Procedures will have to be simple enough for the pilot to make the approach and landing in night weather, at the end of a three day schedule, with all of his personal problems still pending.

Obviously, flying a descending curve approach before landing is a lot different than flying a straight-in final approach. Discussions with airline pilots that currently make curved path approaches indicate that there are several characteristics that make these particular approaches difficult to fly. The most notable is that lack of runway alignment prior to making the commitment to land. Increased difficulty is also directly related to the amount of maneuvering necessary. As maneuvering bank requirements increase, it is necessary to lengthen the wings-level portion of the final approach to keep the approach satisfactory. Acceptable curved path approaches using 15° of bank usually have a wings-level altitude of 500 to 1,000 feet.

All of the curved approaches now in service have one particular characteristic in common - no instrument guidance during the curved portion of the approach. This is not as much of a problem as might be supposed until weather conditions degrade the pilot's ability to judge this portion of his approach. An

example is the Canarsie VOR approach to runway 13L at New York Kennedy Airport. This approach starts with a level segment 90° to final approach. The final turn usually requires a rate-of-descent less than 700 feet per minute, and a bank angle less than 10°. This base to final turn is accomplished easily many times daily under normal VFR conditons. But at night, after a rain storm with visibility at approach minimums, it becomes very difficult to make out the runway in the sea of lights created by the many ground reflections. Even with the turn-in lights for guidance, it is difficult, and the lack of vertical guidance in this instance causes many pilots to rate this approach "dangerous". On this approach, and on other similar curved approaches, pilots usually compensate by flying wide of the correct path to shallow out the turn and to provide more "straight-in" time prior to the flare for landing.

Curved path approaches in current use have three general characteristics: (1) A normal IFR approach with ceiling and visibility minimums such that visual contact is made prior to starting the turn; (2) The curved portion of the approach is completed some prescribed distance from the runway with the last portion of the approach wings-level, and; (3) The final portion of the approach a straight wings-level path of prescribed length from the end of the turn to landing. The normal IFR approach varies from a radar vectored path and altitude with a visual turn onto a long precision guided final approach (River Approach, Runway 13, New York La Guardia) to an ILS path with a visual turn at low Minimums onto a short unguided final approach. (Instrument Guidance System Runway 13, Hong Kong BCC).

The type of initial approach is usually dictated by the general purpose

of the approach. Noise abatement approaches where the object is to avoid overflight of specific areas have an easy entry because they are only done with relatively high ceilings and visibility. Terrain avoidance approaches with relatively low ceilings require more precise guidance initially because of the need to maintain proper clearances prior to entry on the lower curved path. The curved path portion of the approach will usually require as much as 30° of bank when the turns are made at altitudes well above 1,500 feet or at distances of 4 or more miles out on final approach, or as little as 6° when small alignment is required relatively close to the runway.

The vast majority of present airline operations are conducted under IFR while most of the actual weather during these operations is VFR. During routine flight operations, the approach controller will clear the pilot to follow the traffic in front of him once he has reported it in sight. This visual clearance allows traffic to operate at a higher density than is possible when the actual weather conditions present a low ceiling and visibility. Nearly every major U.S. terminal today experiences landing traffic backup and take-off delays when the weather lowers. Projected STOL operations must cope with these same problems. The approach path should be able to accomodate the same traffic density in real IFR weather as when VFR. Pilot workload should be about the same as CTOL operations, and comparable in effort whether IFR of VFR. The passenger should feel as comfortable as he does on the long range wide-bodied jets.

Airline Operational Management is interested in all of the pilot and passenger aspects, plus the ability of the system to follow prescribed profiles with the precision and reliability necessary for FAA certification. Management's ques-

tion is - Will this system do the job as the airlines define it?

The routine airline IFR operation in the United States today has been very successful using the standard ILS as the basic approach. When the airlines went from Category I landing minimums (200 foot ceiling, 1/2 nautical mile visibility) the standard ILS remained the basic approach and the reliability and performance of the equipment necessary to make the approach was improved. This system, with the requirement to have the airplane stabilized (position, airspeed, rate-of-descent, etc.) on this approach by the time the airplane reached the 500 foot level above touchdown zone (ATZ) is safe and efficient. No lesser performance standards are acceptable. Therefore STOL operations must also have some stabilized point in the approach.

Recently an operational evaluation of a two-segment approach was conducted in airline service. The two-segment approach, which has a 6° descent path to intercept the standard ILS, is used as an operational technique for noise abatement. Some of the criteria for this evaluation were : precision must be adequate for use in inclement weather down to Category II minimums; the system must be acceptable to pilots with respect to workload, instrumentation and guidance; procedures must be similar to standard ILS procedures; the system must be adaptable to the current Air Traffic Control environment. The reference of this approach back to the standard ILS is because of the demonstrated success of the standard ILS in airline service. Airline management would expect similar performance in a STOL system using an RNAV enroute capability to intercept and transistion to a MLS (Microwave Landing System).

RESULTS AND DISCUSSION

The results include : brief summaries of letter reports 1 and 2, which are found in appendix 1 and 2 respectively; descriptions of the two basic types of approaches used in the simulation experiment; and the analysis of the collected data. The basic data and the analysis thereof on the balance of the reference flight paths used in the simulation experiment are also found in appendix 3.

Summary of Letter Report 1

Curved path approaches currently in use were researched. Selected approaches were observed from the cockpit during regular airline operations. Many pilots were interviewed as to their experience in flying some of the approaches studied. All approaches involved are listed in Letter Report 1 dated 1/23/76 (Appendix 1).

None of the approaches attempt the curved path portion during IFR conditions. In most instances, the final configuration and airspeed are established prior to starting the curved portion of the approach. The curved approaches that were easiest to fly had the curve completed 4 or 5 miles from touchdown and had some vertical guidance from that point on. The most difficult were those that reached a low minimum, then made the curve while descending without vertical guidance. Ease of flying these approaches improved as the amount of bank required to make the turn decreased.

The procedural characteristics for making operational curved approaches most acceptable are as follows :

1. A minimum straight-in final with vertical guidance.

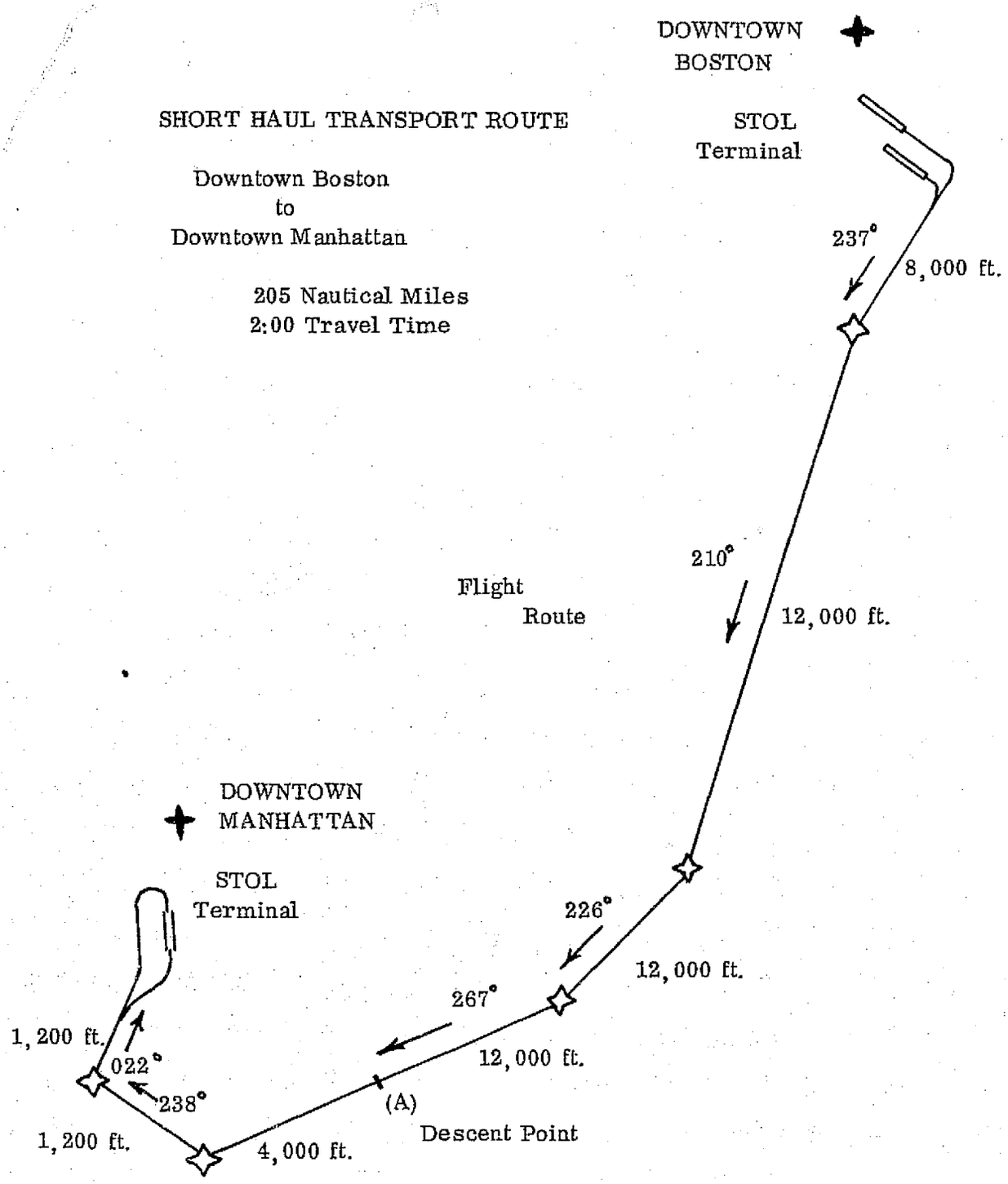
2. Constant descent angle during the final turn and final approach.

3. Bank angles for final turn of 10° average or less.

4. Constant speed during final turn and final approach.

5. Final landing configuration prior to initiating constant descent angle.

A simulation experiment was designed to evaluate curved path approaches that would be used in an assumed STOLAND cummuter route between Boston and Manhattan. A profile of the assumed Boston to Manhattan STOLAND route is illustrated below in Figure 1.



Boston Departure - Take off - Climb on 237 to 8,000 ft. at 17 miles turn to 210 climb to 12,000 ft.

Manhattan Arrival - When inbound on 267 and 12,000 ft. start descent to 4,000 ft. at point (A), turn to 328 continue descent to 1,200 ft. turn to 022 to Manhattan.

Figure 1

Two alternative approaches to satisfy the requirements set down for the assumed Boston to Manhattan STOLAND Commuter Route were examined. The first approach is a path that has a variable downwind segment which intercepts a 180° final turn and a constant 7 1/2° glideslope. The second approach is a level base leg segment intercepting the 7 1/2° glideslope prior to initiating the final turn of 90°. The wings-level point on final approach for both of these approaches varies fron 3/4 N.M. to 5 N.M. from touchdown.

Summary of Letter Report 2

Operational procedures for transition flight from enroute RNAV to time-constrained STOLAND approach paths were defined, with particular emphasis on the flight paths utilizing a 180° turn onto final approach. Initial simulation runs on the 180° turn approaches were flown and analyzed. Figure 2 illustrates a 3 dimensional view of the 180° turn flight paths examined. Coordinates, distances and other details on the flight paths flown are contained in illustrated figures 3 and 4, in the letter report itself, in further discussion which follows and in Appendix 3.

Although only the 180° turns are shown in figure 2, approaches utilizing a 90° final turn would look similar in 3-dimensional sketch. The obvious difference is in the number of degrees of the turn. One objective is designing a series of flight paths with final turns of varying radii is to allow Air Traffic Control (ATC) some flexability in timing and intermeshing incoming flights. For instance, the controller can control the time between waypoint 1 and waypoint 4 by directing traffic into the various illustrated flight paths. The variation in

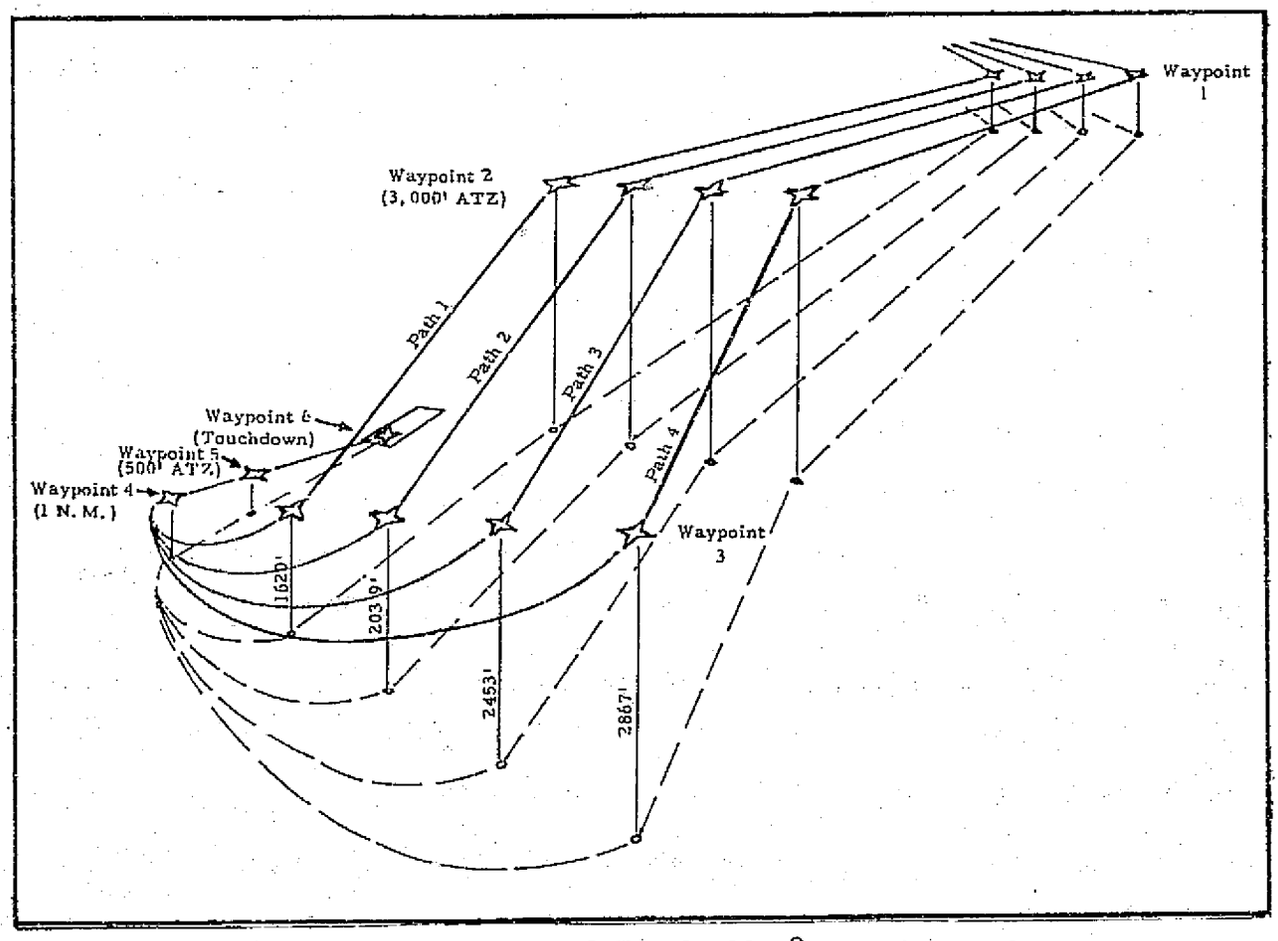


Figure 2 - 3 Dimensional Sketch of 180° Turn Approaches Examined in Initial Simulation Experiment

flight path length is particularily advantageous with STOLAND airplanes, because they show marked limitations in the range of airspeed available during landing approaches. Consider two airplanes arriving on flight path 2. The first is at waypoint 2, the second at waypoint 1 and the two airplanes are 2.2 miles apart. If 3 miles is the minimum separation, then the second airplane could select path 4 and by changing to that path between waypoint 1 and waypoint 2, he would add 1.1 miles to his flight path and would be on path 4 - 3.3 miles behind the first airplane when the first airplane arrives at waypoint 4, still on path 2. The

second airplane would be 2,867 feet above touchdown zone at waypoint 3 on path 4, instead of the originally planned 2,039 feet, therefore his descent from there to touchdown will still be a constant 7 1/2°.

The operation sequence of events on the 180° approaches as illustrated in figure 1 are as follows :

1. Approaching the First Terminal Area Waypoint

   a. Descend on profile descent to initial altitude.

   b. Decelerate airplane and change maneuvering configuration.

   c. Complete approach descent check.

2. Approaching the Second Terminal Area Waypoint

   a. Change to approach configuration.

   b. Extend landing gear.

   c. Engage autoflight and auto control systems.

   d. Change to the landing configuration.

   e. Complete final descent check.

3. Approaching the Third Terminal Area Waypoint

   a. Prepare to transistion to glide path.

   b. Stabilize on glide path before the last 90° of curve is reached.

   c. Stabilize airspeed.

4. Approaching the Fourth Terminal Area Waypoint

   a. Prepare to roll wings level.

5. The Fifth Terminal Area Waypoint is the point of change from RNAV to MODILS and could vary in position anywhere from Waypoint 4 to Waypoint 6.

Approaches Examined by Simulation

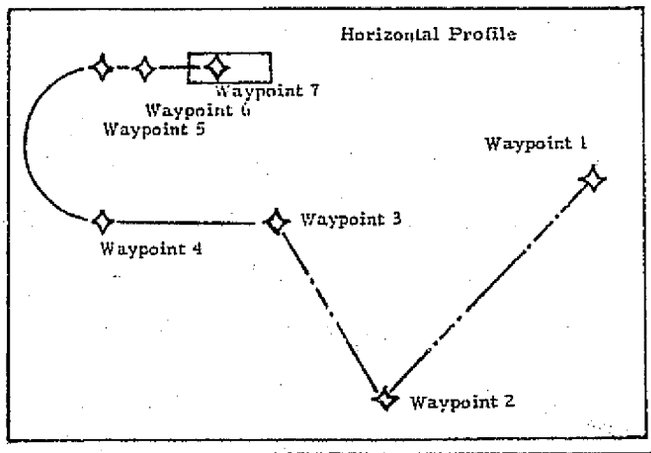
The 10 flight paths that were examined during the simulation experiments are divided into two categories:

1. Flight Paths with a Descending 180° Final Turn

Reference Flight Paths numbers 1, 2, 3, and 4 are of this type. Variations of this flight path involve different wings-level points and different turn radii. Reference Flight Path 3 is typical. Figure 3 below illustrates the horizontal and vertical profiles of Reference Flight Path 3. This path was refined from the simulation of 4/13/76 and is an approach used in the Boston to Manhattan STOLAND route. The refinements are: eliminate a waypoint midway in the final turn, and maintain a constant descent angle from waypoint 4 to touchdown. The procedure for this path starts at Waypoint 1, the airplane is at 120 knots IAS and 3,000 feet above touchdown zone. The airplane transitions to an approach configuration with the landing gear down and partial flaps. The airplane slows and descends in this configuration down to Waypoint 3 as it changes to the landing configuration (autoflight, full flaps, and auto throttles, etc.). The path from Waypoint 3 to Waypoint 4 is straight starting at the initial approach altitude with the airspeed at about 85 knots. At Waypoint 4, the airplane starts a 180° descending turn on the 7 1/2° glideslope. During the final turn the airspeed is stabilized at about 70 knots for the balance of the approach.

Reference Flight Path 3

Way-point	Coordinates x	y	z	Flight Distance Fm Wpt 7
1	30,300	9,400	3,000	59,945
2	13,425	16,075	2,672	40,898
3	3,000	8,000	2,453	27,711
4	- 6,075	8,000	2,453	18,636
5	- 6,070	0	799	6,070
6	- 3,798	0	500	3,798
7	0	0	0	0



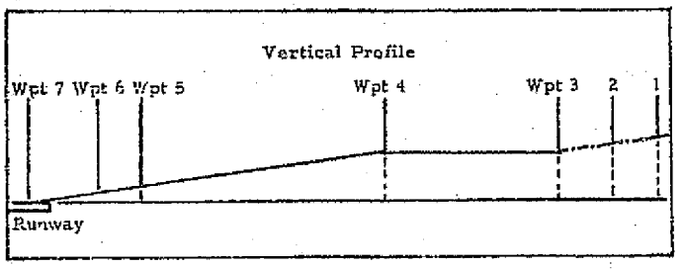


Figure 3

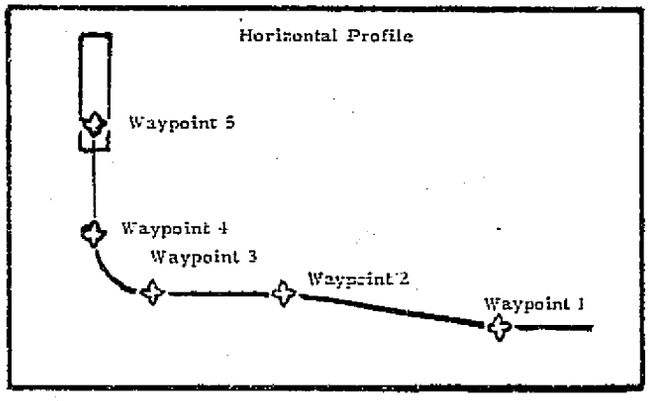
Reference Flight Path 3

2. Flight Paths with a Descending 90° Final Turn

Flight path numbers 5, 6, 7, 8, 9, and 10 contain descending 90° final turns. Variations on this flight path involve different wings-level points and different turn radii. Reference flight path 5 is typical. Figure 4 below illustrates horizontal and vertical profiles of Reference Flight Path 5.

Reference Flight Path 5

Way-point	Coordinates			Flight Distance From Wpt 5
	x	y	z	
1	- 7,000	14,000	1,500	19,025
2	- 5,798	6,453	1,500	11,383
3	- 5,798	2,000	914	6,940
4	- 3,798	0	500	3,790
5	0	0		0



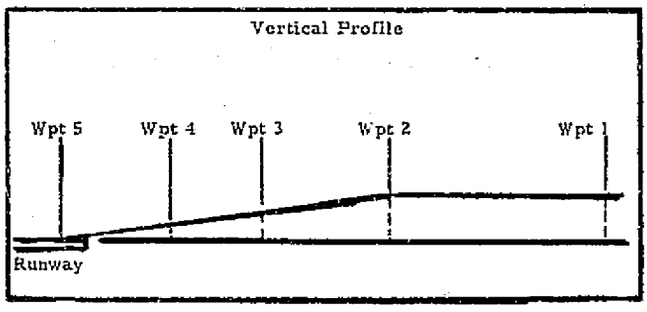


Figure 4

Reference Flight Path 5

In this procedure and all of the other 90° turn approaches the flight simulation is initiated at Waypoint 1. The airplane is in the approach configuration with landing gear extended, indicated airspeed is 85 knots, and at initial approach altitude. The airplane changes to the landing configuration and slows to final approach airspeed by Waypoint 2.

The operational procedure for each of these 90° turn paths is to establish a glide path angle at a constant $7\ 1/2^{\circ}$ starting at Waypoint 2 and continue on that path to touchdown. A level lead-in is used at the initial approach altitude. (See Reference Flight Path Profiles in Appendix 3 for all coordinates and Flight Path distances.)

General Comments The augmentor-wing program has certain limitations for simulation of a jet powered STOLAND airplane. The most notable of these is the inability to demonstrate jet speeds at cruise and the subsequent change from cruise configuration to the approach configuration as an approach is initiated. The portion of the STOLAND route that is within the simulation capability is the approach profile starting where the airplane is in the approach configuration and continues to landing.

Simulation Experiment Simulation experiments were conducted on four different days - 4/12/76, 4/13/76, 8/3/76, and 8/4/76. All simulations were flown to runway 35 (heading 353°) at Crow's Landing, California. Sixty-five data runs were made. Data runs will be identified by the date and the number of the run for that date. (i.e., 04/12-5 is data run 5 on April 12)

1. Simulation on 4/12/76

Table 1 below summarizes the extent of useable data obtained on 4/12/76.

Data Run	Reference Flight Path	Remarks
4/12-0	1	Data Check - descent angle bad.
4/12-1	2	Flight Path Change Check
4/12-2	2	Turn evaluation - descent stop
4/12-3	2	Poor data
4/12-4	2	Data useable
4/12-5	2	Data useable

Table 1
Log of events for the 4/12/76 Simulation

This simulation indicated that the waypoint in the middle of the final turn was unnecessary. The descent angle from initial approach altitude down to the 7 1/2° glideslope was too steep for paths 1, 2, and 3. Upon analysis of this data, the simulation paths were refined. The waypoint in the center of the final turn was eliminated and the altitude of the last waypoint on the downwind leg was adjusted to provide a constant 7 1/2° glideslope from that waypoint to touchdown. (See Letter Report 2, Appendix 2).

2. Simulation on 4/13/76

Table 2 below summarizes the extent of useable data obtained on 4/13/76.

Data Run	Reference Flight Path	Remarks
4/13-1	1	Data useable
4/13-2	2	Data useable
4/13-3	3	Data useable
4/13-4	4	Data useable
4/13-5	2	Change to MLS at Waypoint 5
4/13-6	2	Manual flight - poor
4/13-7	2	Recheck Data
4/13-8	2	Turbulance added
4/13-9	2	Data useable
4/13-10	1	Tailwind 20 kts on downwind
4/13-11	2	Tailwind 40 kts on downwind
4/13-12	2	Wind 023°/20 kts
4/13-13	2	Wind 327°/20 kts
4/13-14	2	Wind Shear - poor data
4/13-15	2	Wind Shear - poor data
4/13-16	2	Turbulance
4/13-17	2	Wind 023^{0} kts + turbulance - poor
4/13-18	2	Data useable

Table 2
Log of Events for the 4/13/76 Simulation

Upon completion of this simulation it was concluded that a 2,000 ft. turn radius for a 180° final turn is unsatisfactory for IFR flight under certain wind conditions. Reference flight paths with a turn radius of 3,000 ft. or more are satisfactory. (See Letter Reports 1 and 2, Appendixes 1 and 2 respectively).

4. Simulation 8/3/76.

Table 3 below summarizes the extent of useable data obtained on 8/3/76.

Data Run	Reference Flight Path	Remarks
8/3-1	5	Data Check
8/3-2	5	Data confirmation - full autoflight
8/3-3	5	Data useable
8/3-4	6	Missed waypoint 1 on capture/vectored to waypoint 2 - minimum speed at 83 kts
8/3-5	6	Data useable
8/3-6	7	Did not capture vertical path
8/3-7	7	Data useable
8/3-8	8	Data useable
8/3-9	8	Data useable - missed capture - re-vectored - set up procedures complicated-skipped HOR/NAV-vectored twice
Wind 323°/40 kts - Wind Turbulence σ = 4.5 ft/sec		
8/3-10	5	Wind changed 4 kts to 40 kts, direction changed 323° to 313° to 323°.
8/3-11	5	Data useable
8/3-12	6	Data useable
8/3-13	7	Altitude Error - insufficient throttle
8/3-14	7	Airspeed constant at approach
8/3-15	8	Airspeed changed at waypoint 3
Wind 023°/40 kts - Wind Turbulence σ = 4.5 ft/sec		
8/3-16	5	Wind direction error
8/3-17	5	Data useable
8/3-18	6	Data useable
8/3-19	7	Revectored several times
8/3-20	8	No data

Table 3
Log of Events for the 8/3/76 Simulation

5. Simulation on 8/4/76

Table 4 below summarizes the extent of useable data obtained on 8/4/76

Data Run	Reference Flight Path	Remarks
8/4-1	7	Wind 023°/40 kts σ = 4.5 ft/sec Bad tape set up
8/4-2	7	Data trip off
8/4-3	7	Wind 023°/40 kts σ=4.5 ft/sec Data OK
8/4-4	8	Wind 023°/40 kts σ=4.5 ft/sec High Airspeed
8/4-5	8	Wind 023°/40 kts σ=4.5 ft/sec Data OK
8/4-6	7	Wind 323°/40 kts σ=4.5 ft/sec Data OK
8/4-7	8	Wind 232°/40 kts σ=4.5 ft/sec Data OK
Simulation Flight Paths Reprogrammed		
8/4-8	9	IP and airspeed in error
8/4-9	9	0 Winds - didn't follow path
8/4-10	9	Didn't fly
8/4-11	9	0 Wind - Data OK
8/4-12	9	Additional wayponts used - added an MLS transition waypoint at 2,000' ATZ
8/4-13	10	0 Wind - airspeed 80 kts - flys below envelope
8/4-14	10	0 Wind - Data OK
8/4-15	9	0 Wind - 6 waypoints - Data OK
8/4-16	10	0 Wind - 80 kts constant airspeed
8/4-17	10	Wind 323°/40kts no turbulance - Data OK
8/4-18	10	Wind 023°/40 kts σ=4.5 ft/sec
8/4-19	3	0 Wind - noticed vertical oscillations between waypoints 1 and 2
8/4-20	3	Wind 323°/40 kts σ=4.5 ft/sec flaps late in procedure
8/4-21	3	Wind 023°/40kts σ=4.5 ft/sec - airspeed stabilized late.

Table 4
Log of Events for the 8/4/76 Simulation

Approach Accuracy

The accuracy at which an approach can be flown with respect to the defined flight path is directly correlated to the minimums to which an operator will fly. Examination of the data of the last 500 feet of descent of the final approach indicates the flight simulation to be consistant and accurate. Figure 5 below displays a vertical error versus altitude. This vertical error was obtained by subtracting the data point altitude (500', 400', 300', etc.) of the recording from the altitude value of the center of gravity at that point. No attempt was made to correct for the small timing error that occurs between the actual occurance of the data and when it was sampled. The plot shows the maximum value, minimum value, and the average of the first 20 approaches flown 8/3/76.

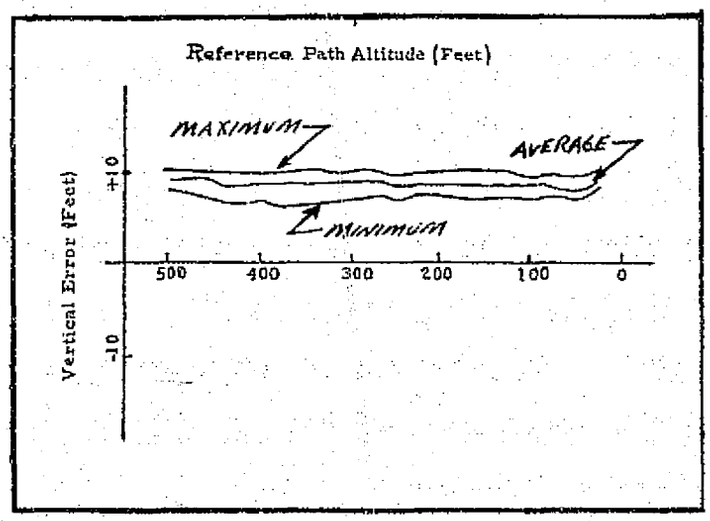


Figure 5
Vertical Error vs. Altitude
Data 8/3/76

Figure 5 includes the approaches with wind and turbulence. The average value of the vertical error (the center line of the plot) is about 9 feet above the flight path at each data point. The consistancy of this error indicates excellent vertical tracking. This much error would result in touchdown just 68 feet beyond the point of intended landing.

Figures 6, 7, and 8 are plots of lateral error versus altitude. Figure 6 shows maximum left (-) and maximum right (+) values and the average (center) of the first 10 approaches flown on 8/3/76. The lateral error of Run 2 and Run 5 had the airplane as much a 77 feet to the right of centerline. The average error at the flight path's 500' point was just 15 feet. This error converged down to about 3 feet left of centerline at touchdown. This performance is also excellent. The fact that the airplane position is within seven feet of either side of the centerline at the 100 foot point on all of the approaches is commendable.

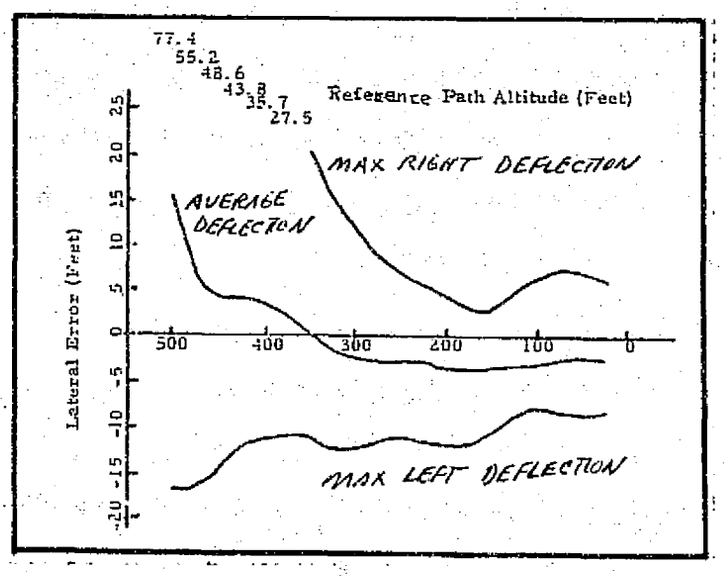


Figure 6
Lateral Error vs. Altitude
Data 8/3/76

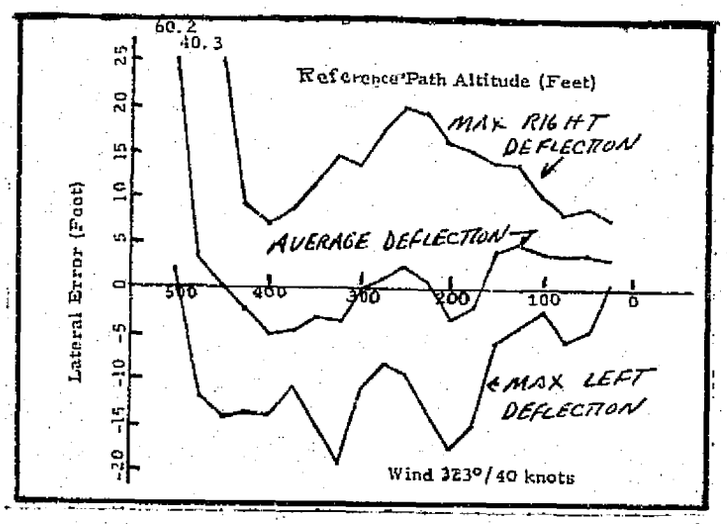


Figure 7
Lateral Error vs. Altitude
Flown 8/3/76 Wind 323°/40 kts.

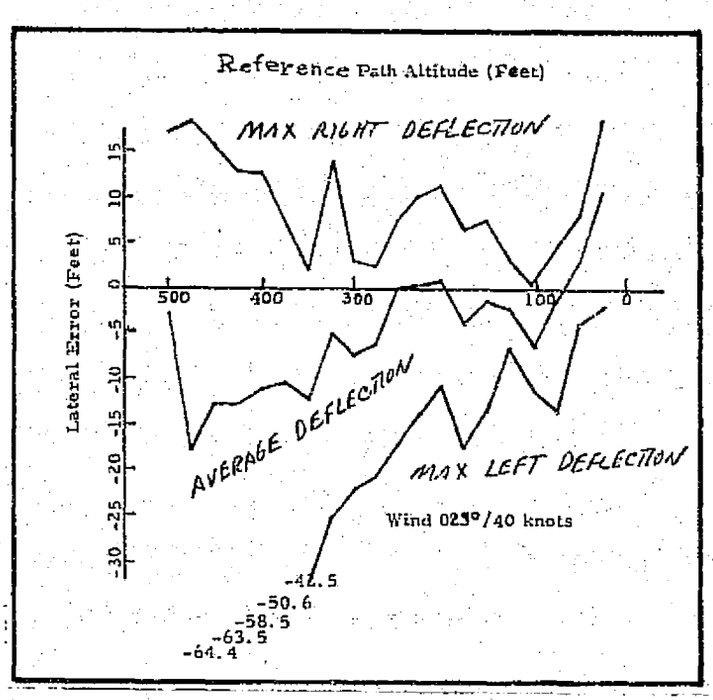


Figure 8
Lateral Error vs. Altitude
Flown 8/3/76 Wind 023°/40 kts.

Figures 7 and 8 (Lateral Error vs. Altitude) are the results of just 4 runs, each with wind. Figure 7 has the wind from the left and is shown to be

more on the positive side of centerline (right drift) than Figure 8, which has its wind from the right. The scatter in the data with only 4 runs makes it difficult to come to any exact conclusion, but the plotted data does indicate that the system can handle the 20 knot direct cross wind component and stay very close to the centerline. The cross wind limitation for Cateogry II CTOL approaches is 10 knots. (Reference 5, United Airlines Category II Report, Reference 6, FAA Advisory Circular 120-20) The average of Figure 7 has the airplane within 5 feet of centerline when below 400 feet altitude. Maximum excursions don't exceed 20 feet. Figure 8, however, is not quite that good. The average is within 12 feet when below the 400 foot altitude point. The maximum excursions are less than 20 feet when below the 300 foot point. For the magnitude of the evaluation cross wind conditions, that is still very good.

From this information, an approach window can be drawn for each 100 feet during the final 500 feet of altitude on the approach. Figure 9 below, is a comparison of a standard CTOL Category II ILS window and the STOLAND window of the MLS of the simulator experiment. Source of data for the standard ILS window is Reference 5, United Airlines Category II Report.

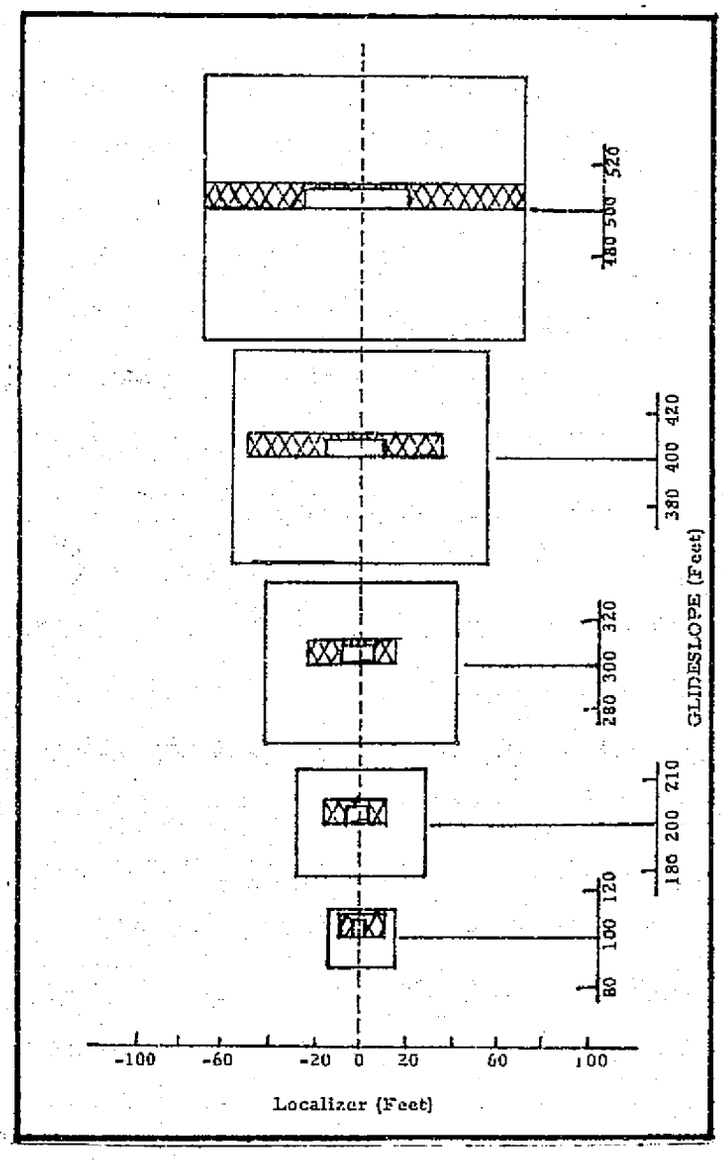


Figure 9

Approach Window

An average Category II ILS is a 3° glideslope with full scale width of 1.4° and a localizer with a 5° width. The Category II approach requires that the airplane be positioned within 1/3 dot (1/6 full scale deflection) of the localizer center line and 1 dot (1/2 full scale) of the glideslope center, prior to and

through minimums. (Reference 5) The large blocks on Figure 9 show the size of the Category II window relative to the STOL window flown. The cross hatched area is the maximum deviations and the small clear box is the average of the deviations of the STOL windows flown.

Data Point	1 Dot Glideslope	1/3 Dot Localizer
100'	12'	14'
200'	23'	38'
300'	35'	42'
400'	47'	56'
500'	58'	70'

Table 5

Category II ILS window dimensions

Table 5 is the category II ILS window DATA, calculated from an average ILS with a 3° glideslope.

The Lateral Error of the STOL MLS approach is well within the category II limits even with the cross wind values double those acceptable on a standard approach. The vertical error of the STOL approach is excellent in comparison and is about half that of the standard category II at the 100 foot point. It sould not be concluded that the STOL MLS approach is significantly better than the standard ILS, because the category II system window is from an inservice system of operational airplanes, runways and equipment and the STOL simulator experiment is just that. But the comparison shown in Figure 9 & Table 5 does

indicate great promise for this type of system if the simulation is representative of what will occur in flight operations.

Path Following

The STOLAND Airplane Flight simulation follows the reference flight path very well from the point of initial capture of the autoflight mode down to the flare point or landing point. Table 6 below is a tabulation of the values of some of the recorded flight parameters at each of the waypoints of Reference Flight Path 5. This table shows the general magnitude of the flight parameters that occured during the data run.

Parameter		Waypoint 1	Waypoint 2	Waypoint 3	Waypoint 4	Waypoint 5 (flare)
Bank		0	0	+6	+11	0
Pitch		+2	+3	-5	-3	-4
Angle of Attack		+2	+3	+2	+4	+4
Lateral Deviation		+off scale	16	24	-8	-8
Vertical Deviation		-150	+200	+20	+20	+20
Altitude		1350	1450	950	500	44
RPM		90	94	93.5	99	98
Airspeed	EAS	84	80	75	70	70
	G/S	62	71	69	59	

Status of Specific Parameters at each Waypoint
Reference Flight Path 5 - Data Run 8/3-3
Table 6

This table shows the general magnitude of the flight parameters that occured during the data run. The bank angle reached 11° right bank, the pitch angly reached 3° nose up and 5° nose down. The altitudes at Waypoint 1 and 2 are different because the function switch for altitude hold is the 5th step of the simulator set up procedure for auto flight. If the pitch trim, the indicated air-speed or the throttle setting are not exact the airplane drifts up or down prior to engaging the altitude hold. After turning on the altitude hold the airplane then makes a capture on the flight path altitude and corrects any error.

On each approach flown, the airplane converged well onto the prescribed lateral path. The bank used during this initial maneuvering was always moderate and was zero within 30 seconds of capture. The vertical path error after capture was usually large and had a large overshoot as the airplane converged on the vertical path. Following the large overshoot, there was an oscillation in vertical path error of about 10 feet. The period of this oscillation was about 17 seconds. This same oscillation was seen in engine RPM, Pitch Angle, and Angle of Attack. The Elevator Deflection trace has a 0.75 c.p.s. oscillation on the track that makes it difficult to determine if the 17 second oscillation is reflected there also.

At Waypoint 2, the point where descent on the $7\ 1/2^{o}$ glideslope starts, the vertical path error immediately shows a large magnitude error. This is primarily due to the lack of a preprogrammed transition. The ability of the simulation to null out this error indicates that a simple nose down command prior to waypoint capture might be all the transition necessary to correct this point. The change in pitch angle during this transition is rela-

tively small and within 2° of the angle required to hold the flight path steady after the final turn is complete. The lateral deviation at this point shows a 1/2 c. p. s. oscillation which is not followed by bank angle nor was it detected while observing the flight instruments. The auto-throttle usually retarded the engines to 89% momentarily at this transition point, and the airspeed usually slowed to final approach speed plus about 5 knots.

The airplane descent angle and speed was established as waypoint 3 was reached and the 90° final turn started. The roll in and roll out by the airplane was smooth and with very small overshoot of the required bank angle to maintain the path. Note: A 2,000 foot steady level turn radius theoretically requires 12° of bank. During these descending turns the bank usually was between 11 and 15°, (See Table 7)

Table 7 below is a summary of flight parameter variations between waypoints for Reference Flight Path 5.

Para-Meter	Waypoint	Time	Remarks
Bank Angle	Wpt 1 to Wpt 2	72 sec	25° left bank until convergent on path 14 seconds then stays level.
	Wpt 2 to Wpt 3	37 sec	Level
	Wpt 3 to Wpt 4	27 sec	Rolls to 15° bank, stays for 11 seconds, then shallows to 11°
	Wpt 4 to Wpt 5	38 sec	Rolls level in 5 seconds, has slight roll oscillations of 4.5 second period.
Pitch Angle	Wpt 1 to Wpt 2	72 sec	$\pm 6^{\circ}$ until stabilized on vertical path.
	Wpt 2 to Wpt 3	37 sec	$+4^{\circ}$ for 6 seconds, $+3^{\circ}$ for 3 seconds then pitches down to -5° in a 3 second period then constant.
	Wpt 3 to Wpt 4	27 sec	Increases from -5° to -3° during turn.
	Wpt 4 to Wpt 5	38 sec	Settles to a constant -4°.
Lateral Path Error	Wpt 1 to Wpt 2	72 sec	Overshoot right to left & converges to +20' in 50 seconds.
	Wpt 2 to Wpt 3	37 sec	Nearly steady +14' for 25 seconds, then variable to waypoint 3 to +30' average.
	Wpt 3 to Wpt 4	27 sec	Small variations $\pm 3'$ decreasing from +30' to $\pm 8'$.
	Wpt 4 to Wpt 5	38 sec	Moves immediately to -8' holds constant.

Table 7
Flight Parameter Variations Run 8/3-3 RFP 5

Para-Meter	Waypoint	Time	Remarks
Vertical Path Error	Wpt 1 to Wpt 2	72 sec	Large correction initially, converging on 0 with 4 1/2 cycles of 17 second period.
	Wpt 2 to Wpt 3	37 sec	200' ± variation as the vertical path changes to 7 1/2° glide slope, then converges up to +20' error.
	Wpt 3 to Wpt 4	27 sec	Slight increase to +30' in 15 seconds, then steadies at +20'.
	Wpt 4 to Wpt 5	38 sec	Constant +30' error.
Elevator Deflection	Wpt 1 to Wpt 2	72 sec	Two deflections ± as mane uvering to flight path is completed, constant after that.
	Wpt 2 to Wpt 3	37 sec	Decrease from +2° to -1° for initial transition comes back down to -1°, then steadies on 0.
	Wpt 3 to Wpt 4	27 sec	Decreasing to a steady -1°.
	Wpt 4 to Wpt 5	38 sec	One deflection to +2° then steady on 0.
RPM	Wpt 1 to Wpt 2	72 sec	Oscillations with a 17 second period 91-94%.
	Wpt 2 to Wpt 3	37 sec	94- 89% in 5 second then nearly steady at 93%.
	Wpt 3 to Wpt 4	27 sec	Slowly increased to 96% for 25 seconds then abruptly to 99%.
	Wpt 4 to Wpt 5	38 sec	Holds 99% for 12 seconds slowly decreases to 96% at flare.

Flight Parameter Variations Run 8/3-3 RFP 5 (continued)

Parameter	Waypoint	Time	Remarks
Air-Speed	Wpt 1 to Wpt 2	72 sec	Oscillations ±2 knots about 84 knots with a 17 second period.
	Wpt 2 to Wpt 3	37 sec	Slowly decreased to 75 knots.
	Wpt 3 to Wpt 4	27 sec	Slowly decreased to 70 knots.
	Wpt 4 to Wpt 5	38 sec	Constant 70 knots.

Table 7 continued

Flight Parameter Variations
Run 8/3-3 RFP 5

(Summaries of Flight Parameter Variations for Reference Flight Paths 6, 7, and 8 are found in Tables A3-1A, B; A3-2A, B; and A3-3A, B respectively in Appendix 3.)

The 90° final turn was completed at Waypoint 4. At the completion of the turn, there were no noticeable transient variations of the flight parameters. The engine RPM usually retarded from 99% to 95-96% as the point of

Flare was reached.

Overall, the approaches were very good. The performance compares well with the standard approaches currently being flown in airline operations today. During CTOL operations, the standard ILS airspeed is required to be stabilized within 5 knots of the required speed for the last 500 feet of the approach (Reference 1. NASA CR-2515 Operational Flight evaluation of the two-segment approach for use in airline service). During the simulation experiment the airspeed of the STOL approach was stabilized within 2 kts of the required speed.

The bank angle limitation on final approach during CTOL autocoupled, standard ILS is 15°. The STOL approach did not exceed this within $90^{o}$of the final approach heading. Establishing the final configuration prior to the $7\ 1/2^{o}$ descent and establishing the glide path prior to making the final turn provides a relatively unstabilized final approach. The bank required to make the final turn is shallow enough to be acceptable to the pilot for IFR operations. Although each approach was equally stabilized, the 30 seconds on final, on reference flight paths 5 and 6 was not as comfortable for the observer as was the 50 seconds on final on reference flight paths 7 and 8. The longer time permitted better opportunity for the pilot to cross check and assure that all parameters were stabilized prior to landing.

Wind Effect

The effect of wind and turbulance on these approaches is very similar to the effect on CTOL approaches.

Wind changes the ground speed between waypoints and subsequently the time to fly.

The wind and turbulance caused changes in the analog data traces for Vertical Error, Pitch Angle and RPM. The magnitude of the oscillation increased and the period of the oscillation decreased.

The bank angle required to make the flight path turns was varied. A quartering tailwind produced an increase in bank angle requirements. The 2,000 foot turn radius of Flight Path 1 required 26° of bank during the initial part of the turn. This large bank would be unsatisfactory for IFR operations. During the last 90° of turn where the wind is a headwind, the bank requirements are decreased and the system performance improved. (See Wind Effect, Appendix 4)

Pitch Attitude

Airplane pitch attitude during approach is important to CTOL airline operations for two reasons: (1) The passengers are more comfortable and feel more secure of they feel that the airplane is straight and level at all times. Passengers also demand an out-the-window view so that even in coordinated flight where the airplane feels level, an extreme attitude is also unacceptable. (2) During take off and landing, the passengers don't like to feel tipped back or forward. The sensation of leaning backward during take off is usually more acceptable than the feeling of falling-out-of-the-seat during an approach or during rapid deceleration.

Passengers in a standard airline type seat with seat belt fastened, have a definite falling-out-of-the-seat feel when airplane deceleration exceeds 0.2g. With this deceleration a person has to consciously hold his head back to keep from being tipped forward. A stabilized 11.5° descent attitude of the passenger seat would cause a 0.2g. deceleration feel. A 7.5° descent angle of the seat would produce a 0.13 g. deceleration feel.

The analog trace of the airplane's pitch attitude during the STOL simulation experiment indicated the pitch attitude during level flight is generally 4 to 5 degrees nose up. The approach attitude on the stabilized $7\ 1/2^{\circ}$ glide path is about 4 to 5 degrees nose down. These steeper pitch attitudes were generally associated with glideslope transistions with airspeeds higher than that on final approach. These steep angles last only a short period of time and do not appear to be extreme enough to cause undue adverse passenger reaction. However, in the transition area at the start of the $7\ 1/2^{\circ}$

glide path a large pitch attitude change occurs. The airplane rotates through 8 or 9 degrees in 7 to 10 seconds, which could be uncomfortable to passengers. A transition of 15 to 20 seconds through that pitch change would be a lot less noticeable. If the STOL passenger seats were installed in the airplane with 4 or 5 degrees backward tilt, the falling-out-of-the-seat feel would be no different than CTOL operations. With the exception of the transition onto the glide path and into the flare prior to landing, the airplane has good flying qualities with respect to pitch. Observations of the Attitude Indicator and Flight Director System verify these flying qualities.

The other attitude parameter, bank angle, is of more concern to the pilot than to the passenger. The maximum bank reached during the approach phase of the experiment was 26°, and that was for only a short period of time. That angle wouldn't be noticed by a passenger unless his out-the-window view gave him a good reference with which to judge the bank just at the time it occurred. The bank limit in CTOL operations is 30°

Simulator Operation

There are a lot of steps required in the procedure to start a simulator run. The following are the steps required to operate the simulator:

1. Main system switch - on	Starts the simulation
2. Autopilot - on	Autoflight for the lateral path
3. Autothrottle - on	Autoflight for the IAS hold that has been programmed
4. Altitude - on	Autoflight for the vertical path

5. Heading - on Enter desired heading	To establish an intercept heading so the programmed path can be intercepted and captured
6. TACAN - on	To activate navigation facilities
7. Horizontal navigation - on	Coupling to lateral path
8. Flight path - select	Four choices of reference flight path
9. Flight director - on	To display flight director command
10. Orientation - select	North up is displayed with selection of flight path. This function can change display to heading up or course up.
11. Scale - select	To change the size of the display
12. Waypoint - select	Using the entry panel enter the number of the waypoint where the flight path is to be intercepted

This routine would be satisfactory for an airplane experiment where the pilot maintains proper heading, airspeed and altitude while flying towards the proper waypoint while the system operator set the system up. The airplane's path between approaches is usually the same because each approach would start from the same waypoint. To use this many steps to turn on an operational system is unrealistic. In an operational environment many of these functions would be part of the enroute portion of the flight. An operational procedure for the start of an approach should start with a set of initial conditions that are indicative of enroute flight and that are "pre-set" prior to operating the simulation.

CONCLUSIONS AND RECOMMENDATIONS

1. The curved path approaches currently in use with CTOL operation in the United States are flown VFR and usually do not have vertical or lateral guidance during the curve. The current STOL operations in the United States and Canada should be examined for their characteristics.

2. The operational procedures for flying STOL curved path approaches are satisfactory for auto-flight operation. These should be evaluated for Flight Director and other pilot controlled operations.

3. The flight simulation experiment indicates good flying characteristics and good accuracy of the flight paths used. This experiment should be extended to actual airplane flight experiments.

4. The curved paths designed for an assumed STOL route between Boston and Manhattan are satisfactory and followed well by the Aug-wing simulation.

5. A 2,000 foot turn radius is unsatisfactory for a 180° turn with certain winds. A 3,000 foot or larger turn radius is satisfactory. The smaller turn radius is satisfactory for turns up to 90°.

6. The accuracy of the STOLAND simulation is as good as that required of CTOL Category II operations.

7. The curved paths are satisfactory during heavy cross winds with turbulence. The STOLAND system should be evaluated with wind shear variations.

8. Passenger comfort should be evaluated for a STOLAND system by considering the passenger seat pitch angle during transistion and on a steep final approach.

9. The simulator set-up steps are cumbersome for repeated simulator approaches. The softward program should be examined for changes that would make a simulator experiment more efficient.

REFERENCES

1 -G.K. Schwind, J.A. Morrison, W.E. Nyler, and E.B. Anderson, NASA Contractor Report - NASA CR-2679 - Flight Evaluation of Two-Segment Approaches Using Area Navigation Guidance Equipment (Prepared by United Airlines, Chicago, Illinois, 60666 for Ames Research Center) April 1976.

2 -G.K. Shcwind, J.A. Morrison, W.E. Nyler, and E.B. Anderson, NASA Contractor Report - NASA CR-2515 - Operational Flight Evaluation of the Two-Segment Approach for Use In Airline Service (Prepared by United Airlines, Chicago, Illinois, 60666, for Ames Research Center), April 1975.

3 -J.A. Morrison, Letter Report 3 NAS 2-9028 Operational Requirements For Flight Control and Navigation Systems for Short Haul Transport Aircraft (Prepared by AVCON, Aviation Consultants, Inc. Broomfield Colorado, 80020) July 1976.

4 - United Airlines - , Category II Report March 16, 1970 with FAA Certification Ammendment No. 7 to Operating Certificate No. 11

5 - FAA Advisory Circular 120-20, Category II Performance Criteria.

NASA CR-137975

November 1976

APPENDIX 1

Letter Report 1

NAS 2-9028

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LETTER REPORT I
NAS 2 - 9028

Operational Requirements for Flight Control and Navigation Systems for Short Haul Transport Aircraft

Prepaired By: John A. Morrison

For

National Aeronautics & Space Administration
Ames Research Center
Moffett Field, California 94035

For the Period

September 23, 1975 through January 23, 1976

John A. Morrison

SUMMARY

There are many curved path approaches in routine airline use today. These approaches are used for noise abatement and terrain avoidance. The ease of flying each approach is related to the amount of turn, bank required, size of airplane and proximity to the ground of the curve. Large turns, large airplanes and close to the ground tend to increase the difficulty in flying a curved path approach. The defined simulator tasks for evaluation of the curved path approaches are a 90 degree turn to final at 4 miles, a 90 degree turn to final at one mile, a 60 degree turn to final at one mile and a 180 degree turn to final within one mile.

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INTRODUCTION

AVCON, Aviation Consultants submits this report in accordance with reporting requirements of contract NAS 2-9028. This report includes the preliminary results of Task 1. Determine curved paths that are currently in use at United States Airports, examine projected curved descending approach paths (e.g. La Guardia, Washington National, and Aspen) and use the characteristics (e.g. required deceleration profiles, bank angles, etc.) identified in such approaches to define one or more simulator tasks for evaluation of the curved path approaches.

The major emphasis in this contract is the pilot operational view of how such a system will operate in airline service. This task thus becomes a major stepping stone in defining how descending curved paths are currently being used.

NASA policy, as enunciated in Policy Directive NPD 2220.4 dated September 14, 1970 is that measurement values employed in NASA contractor reports shall be expressed in the International System of Units (SI). The subject matter of this report, however, pertains to a field in which SI is currently not in use nor is it the accepted standard for future use.

In the interest of assuring that material herin is clear and useful to those concerned, conventional aviation units for altitude, distance, and airspeed appear in this report.

EVALUATION PROCEDURE

The work for Task 1 was initiated by researching the curved path approaches currently in use. Selected approaches were observed during regular airline operations from the cockpit. Many pilots were interviewed as to their experience in flying some of the other approaches under study. The approaches were placed in three major categories and several typical examples of each of these categories selected for detailed study. The basic characteristics of these approaches were then placed into three approach procedures to be used as the initial simulator tasks for evaluation of the curved path approaches.

EVALUATION RESULTS

The basic review of curved path approaches currently operational include an interesting approach in use in Hong Kong BBC and one in Juneau, Alaska. In addition the Microwave Landing System approaches that use a 6 degree approach path were also considered.

The MLS approaches are as follows:

1. Bellaird, Michigan RW-2 3 degree G/S
2. St. Paul, Minnesota Downtown Airport RW 30 3 degree G/S
3. Aspen, Colorado RW 15 6 degree G/S
4. Fullerton, California RW 6 degree G/S

The curved path approaches are as follows:

1. Aspen Tacan B RW 15
2. Chincoteague Island VOR/DME RW 10
3. Dallas - Fort Worth Vine Visual RW 17
4. Dallas - Fort Worth Pike Visual RW 35
5. Hong Kong BCC IGS RW 13
6. Juneau IDA DME RW 8
7. Los Angeles 45 degrees Visual RW 25
8. Minneapolis - St. Paul River Visual RW 22
9. Minneapolis - St. Paul Downtown Visual RW 11
10. Minneapolis - St. Paul Braemar RW 11
11. Minneapolis - St. Paul 494 Visual RW 4
12. Minneapolis - St. Paul 35W Visual RW 11
13. Minneapolis - St. Paul Southport RW 4
14. New York - Kennedy VOR RW 13
15. New York - La Guardia River RW 13
16. New York -La Guardia Expressway RW 31
17. Phoenix Black Canyon RW 8
18. Phoenix Power Plant RW 26
19. Seattle - Tacoma Visual Bay RW 16
20. Washington D. C. River RW 18
21. Washington D. C. LOA RW 18
22. Washington D. C. Mount Vernon RW 36

The MLS approaches that use a 6 degree glide slope are worthy of comment. They are used by airlines flying the DeHavalan Twin-Otter Airplane. Both approaches are used for terrain avoidance. At Fullerton there is an obstacle close to the airport that has just 160' clearance on the 6 degree path. At Aspen the airport is in a box canyon with rapidly rising terrain on the open end also. With both of these approaches the minimums are sufficiently high that the 6 degree glide slope serves as a constant path for a visual approach to the runway. In each case the path provides vertical clearance while positioning the airplane safely over the runway threshold for a landing.

Table 1. summarizes the 14 approaches chosen to represent these three categories. Appendix A contains a sketch of the approaches with a short description of each.

The curved path approaches fall into three general categories.

1. A curved path high above the ground that intercepts a standard type final approach with a relatively long straight in approach.
2. A straight entry to a curved path at a medium altitude above the ground that serves as a final turn to a much shorter final approach.
3. A straight IFR type approach to a curved path at a low altitude which is the final turn to a very short final approach.

The approaches that fit the first category are:

New York La Guardia River Visual RW 13

Dallas - Ft. Worth Pike Visual RW 35

Phoenix Black Canyon RW 8

Seattle Visual Bay RW 16

Los Angeles 45 Visual RW 25

These approaches are routinely flown by airplanes of all sizes and are not difficult to accomplish. All are used for noise abatement and are authorized only during VFR flight conditions. The turn to final approach is sufficiently high above the ground to permit up to a 30 degree bank turn with out any undue concern by the pilot. The La Guardia and Seattle approaches use an ILS for assistance on the final approach. If there were adequate guidance for the turn in, either the 45 degree intercept at Seattle or the 90 degree intercept at La Guardia, these approaches could operate at ILS minimums. The restriction is because of the navigation problem of staying over water during the entry and the ATC limitations as to the angle of final turn during IFR conditions.

Three approaches were selected to represent the second category:

Minneapolis - St. Paul 494 Visual RW 4

Minneapolis - St. Paul Braemar Visual RW 11

Minneapolis - St. Paul Downtown Visual RW 11

The approaches are similar to each other. The major difference being the angle of intercept that each approach uses. The distance over which the final turn is made is about the same so each approach would use a different bank angle for the

turn while keeping the same rate of descent. This type approach is easily flown by all sizes of airplanes. The approach path in each case is over an area that is less sensitive to noise than a straight in path to the runway. The turn to final is accomplished at a medium altitude (800 to 1000 ft. AFL). As the turn requires a greater bank angle pilots of larger airplanes tend to fly wide of the approach path so that they may complete the final turn at a slightly higher altitude. The pilot thus has more time on final to assure that his descent path to the runway is correct well before being committed to land.

When the runway has an ILS and it is operating, the pilots elect to use it for vertical guidance for a fast accurate check on their descent angle.

The third category of approaches selected are these six:

Hong Kong BCC ICS RWY 13

Aspen VOR RWY 13

Juneau IDA DME RWY 8

La Guardia Expressway RWY 13

Kennedy VOR RWY 13

Washington National River RWY 18

This category approach has its curved path closest to the ground and is the most difficult to accomplish. The approaches are designed for terrain avoidance and noise abatement. The weather minimums are the lowest of the three categories because the curved path results after completing a precision or non-precision approach down to some weather minimum. Under certain weather conditions these approaches are very difficult to fly.

The characteristic of a curved approach that makes it difficult to fly is the lack of runway alignment prior to the commitment to land. If the curved path is completed high enough above the touchdown zone to allow the pilot to feel stabilized the approach becomes "easy". If the airplane flight varibles (pitch, bank, airspeed, descent rate, etc.) are still in a transient state close to touchdown the approach becomes "difficult" and the pilot uncomfortable even though his performance is good.

The Hong Kong approach was selected even though it is not in the United States because of its peculiarities. It is a terrain avoidance approach that requires a turn of 47 degrees in one and one quarter miles using a 25 degree bank. This turn has to use that much bank in order to align with the runway at least one half mile from touch down. The Juneau, Alaska approach is a similar terrain avoidance approach that is very easy to accomplish as it only requires a turn through 14 degrees which can be done with a 6 degree bank and be aligned with the runway three quarters of a mile from touchdown. In both instances the airplanes are stabilized in the same constant descent.

The Aspen,Colorado approach is also a terrain avoidance approach that has a small turn required close in to the runway. This approach can be made by staying on a straight line towards the VOR then using a 10 degree bank to make the 19 degree turn for runway alignment. Yet most pilots prefer to make a large "S" turn using 25 degrees bank at a higher altitude in order to get as stabilized as possible (fewer changing flight variables) prior to reaching the runway. One look at the airport and the reason for this is apparent. The ground rises

quite rapidly on three sides of the runway such that a missed approach from anywhere close to the runway is a real hazzard.

Another airline using an airplane capable of a six degree approach path prefers to use a steeper path straight in rather than fly the curved path with a standard descent.

In New York there is a curved approach to each of the major airports that is difficult to fly. The La Guardia Expressway approach to runway 13 uses a 30 degree bank turn for a 90 degree turn. The first turn down the expressway is very routine even though the airplane is in a steep descent. The final turn which requires a shallowing out of the descent as well as a large turn to runway alignment becomes a challenge to the airline pilot every time it is attempted. Large airplanes don't even attempt the approach. Meanwhile at the other New York airport, Kennedy, the Canarsie VOR approach to runway 13 is a 90 degree turn that only requires an eight degree bank, is conducted at a constant rate of decent and is still almost as difficult to fly. The pilots of the larger type airplanes tend to fly wide on this approach so that the turn can be completed and all the flight variables stabilized well before the runway threshold. At night when it has been raining, the approach into runway 13L becomes very difficult as the runway reference lights are hidden in a sea of side lights and reflections.

Under these conditions the approach, which is a shallow bank, constant descent, and has sequence lighting for runway alignment, is still difficult without any vertical guidance.

The River approach into Washington National becomes the most of all, if

it is followed precisely. It requires several turns in both directions prior to runway alignment. The approach is flown at a constant descent that is slightly less than three degrees. The last lead-in light is at a point such that the airplane is turning left as it passes over the light then must turn back right in order to align with the runway. Most pilots prefer to avoid this "S" turn down low and do so by flying down the east bank of the River, which is the border of a prohibited area, and then making only a right bank turn for the final alignment with the runway.

A sketch of each evaluation approach is found in Appendix A. The approaches are also summarized in Table 1 page 12.

Examination of these curved path approaches shows a lack of vertical guidance. In most instances adding this element into the approach would increase its acceptability for routine airline operation. Large bank angles, high descent rates and large turns do not present particular difficulties for any size airplane provided they are accomplished high enough above the surface that the flight variables can be stabilized prior to the commitment to land. The descent path angle does not appear to relate to the difficulty in flying a curved path approach. A steep path guided, is preferred to a shallow path unguided. There is a relationship to difficulty in the angle of bank in the low curved path. Bank angles of 10 degrees or less do not appear to cause an increase in difficulty. There is even a suggestion that greater bank angles would be acceptable if proper guidance were to accompany such need.

CURVED APPROACH SUMMARY

Approach	Rate of Descent at 135 KTS 5 mile point	10 mile point	Bank angle used	Ease of Flying
New York La Guardia	0	715	30	1
Dallas - Ft. Worth RW - 35	1435	787	30	1
Phoenix RW - 8	835	835	30	1
Los Angeles RW 25	1798	715	30	1
Seattle RW - 16	715	715	15	1
Minn. - St. Paul 494 RW - 4	955	955	22	2
Minn. - St. Paul Braemar RW 11	955	955	27	2
Minn. - St. Paul Downtown RW - 11	955	955	30	2
Hong Kong RW - 13	715	700	25	5
Aspen RW - 15	1075	715	10	3
Juneau RW - 8	900	700	6	2
New York La Guardia RW - 13	1195	715	30	5
New York, Kennedy RW - 13	669	715	8	4
Washington National RW - 18	715	620	10	5

Table 1.

SHORT HAUL TRANSPORT ROUTE

Downtown Boston to Downtown Manhattan

The Downtown Boston facility is assumed as no present facility exists. Such a facility could be constructed in several neighborhoods by utilizing a city park or through clearing one of several slum areas.

The Downtown Manhattan facility is almost in being now. The lower west side port area that is no longer in use.

Each terminal is assumed to be within 15 minutes of the average Boston-New York commuter.

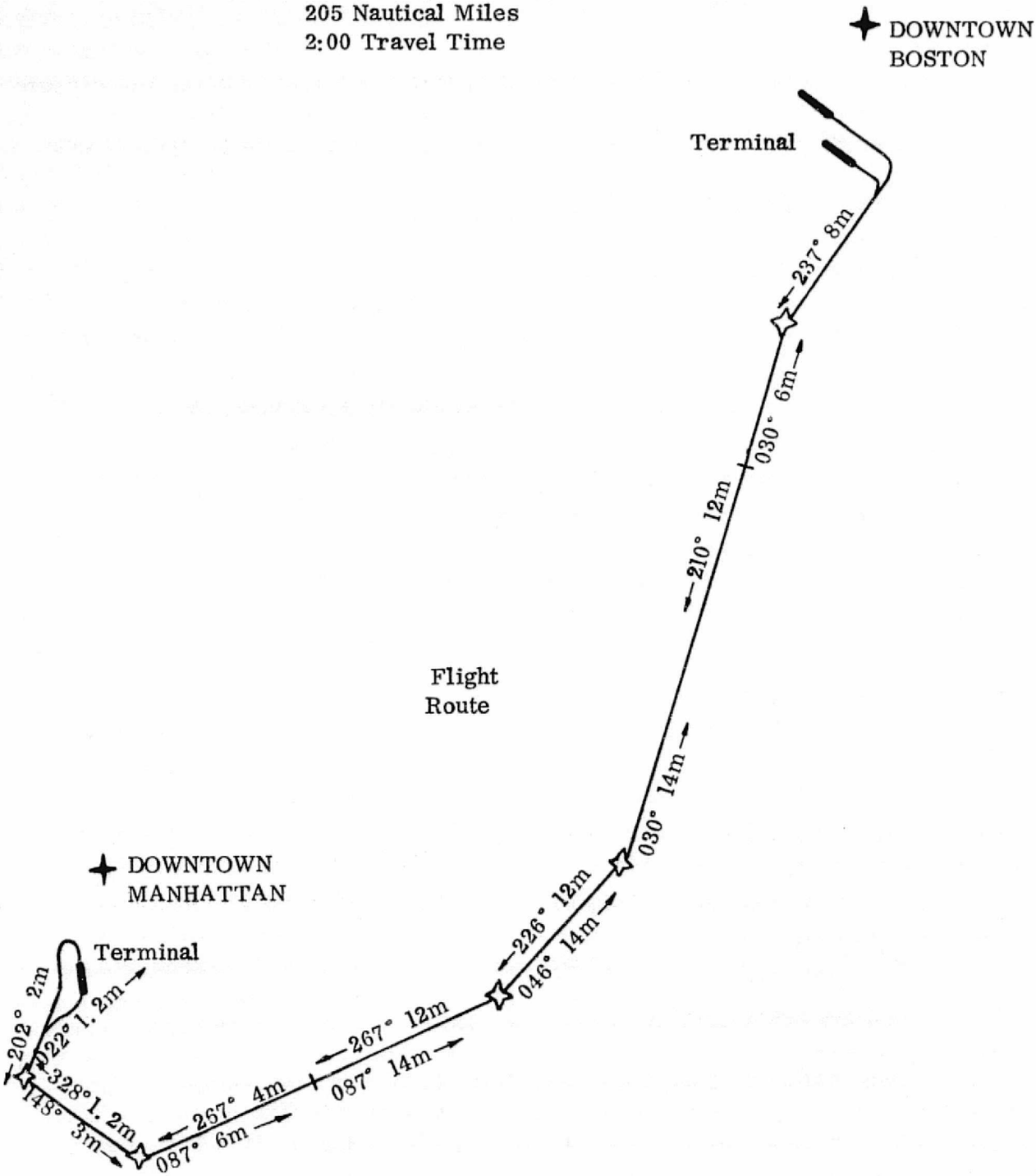
An office to office time sequence of the flight would appear like this:

Downtown Boston	9:00
Taxi cab to terminal	9:15
Check in and board	9:25
Departure terminal	9:30
Take off	9:35
Reach 10 mile point	9:44
Cruise 250 kts.	
185 miles 44 min.	
if 120 miles,	
flownat 300 kts 40 min.	
Reach 195 mile point	10:28
Landing	10:37
Arrival terminal	10:41
Taxi cab from terminal	10:45
Downtown Manhattan	11:00

This plan will reduce the present travel time from downtown Boston to downtown Manhattan by about 3:20.

SHORT HAUL TRANSPORT ROUTE

Downtown Boston to Downtown Manhattan
205 Nautical Miles
2:00 Travel Time



Boston Departure

Take off - Climb 237 to 8m at 17 miles turn to 210 climb to 12m

Manhattan Arrival

Inbound 267 4m to point (A) turn 328 descend to 1.2m turn 022 to Manhattan

SIMULATOR TASK DEFINITION FOR EVALUATION OF THE CURVED PATH APPROACHES

Analysis of the curved path approaches currently in use suggest four approach patterns should be evaluated for an Assumed Short Haul Transport Route between Boston and Manhattan.

1. Descending downwind with 180 degree final turn with one mile base.

2. Descending 60 degree or less intercept to a final turn initiated at one mile.

3. Descending 90 degree intercept to a final turn within one mile.

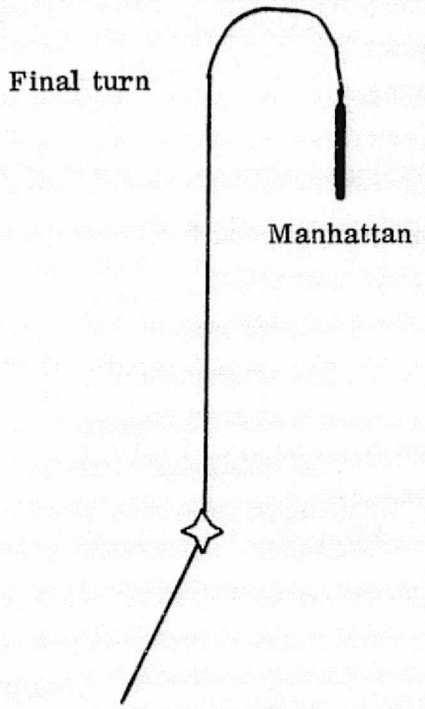
4. Level 90 degree intercept at four miles to a final turn.

These patterns would fit the assumed runway positions of a Boston-Manhattan route and could reasonably be expected to exist in the time constraints of the Short Haul Transport.

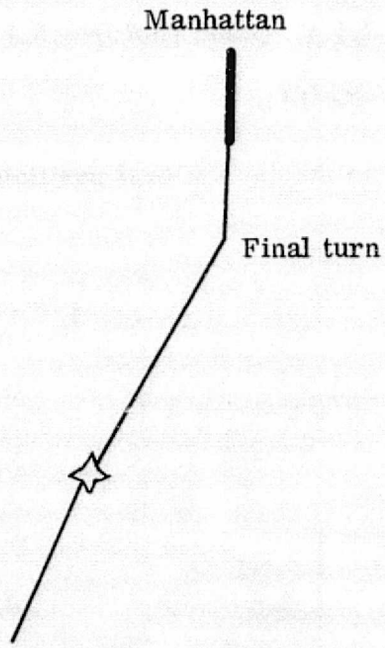
Each of the four simulator task for evaluation of the curved path approach will utilize one of these approach patterns to simulate the arrival into the terminal area from an RNAV route from Downtown Boston to Downtown Manhattan. Each simulator experiment should include the test parameters desired for c urved path evaluation as found on page 17, in the measurements taken.

CURVED PATH APPROACH SIMULATOR TASKS

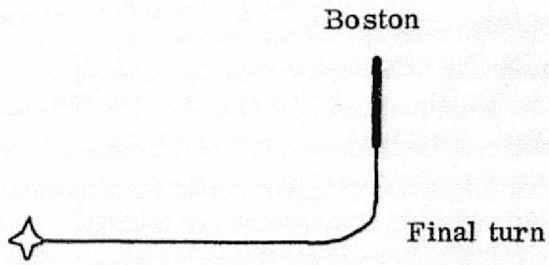
Boston, Mass. to New York, N. Y. Manhattan



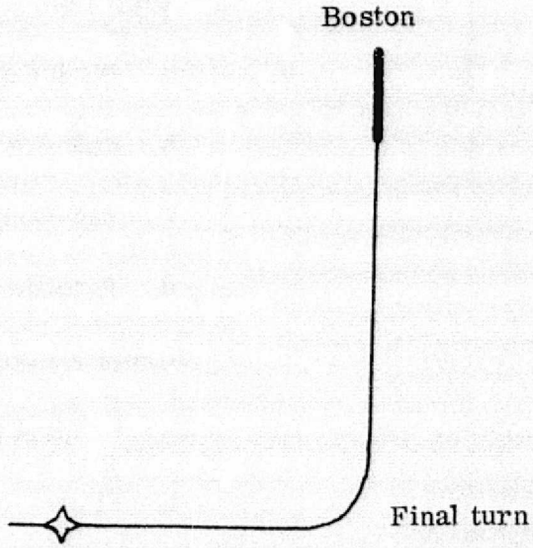
Task 1. Descending down wind with 180 degree final turn within one mile base



Task 2. Descending 60 degree or less intercept to a final turn within one mile



Task 3. Descending 90 degree intercept to a final turn within one mile



Task 4. Level 90 degree intercept at four miles to a final turn.

TEST PARAMETERS DESIRED FOR CURVED PATH EVALUATION

The test parameters recommended for an evaluation of the operational requirements of curved path approaches should be devided into three groups: 1.) Airplane position, 2.) Pilot Control, and 3.) Airplane configuration. These should be measured as a function of time or distance such that it could be related to the navigational position of the airplane during an approach.

1. Airplane Position
   a. Vertical deviation from desired flight path
   b. Lateral deviation from desired flight path
   c. Pitch attitude
   d. Roll attitude
   e. Heading
   f. Airspeed
   g. Longitudinal acceleration
2. Pilot Control
   a. Pitch Control
   b. Roll Control
   c. Yaw Control
   d. Throttle Control
3. Airplane Configuration
   a. Landing Gear
   b. Flaps
   c. Other Devices, deflectors, etc.

The operational considerations for the curved path evaluation should determine the following:

1. Altitude and distance from touchdown for wing level flight.

2. Flight path angle. If two-segments are used the transistional altitude for the second segment.

3. Turn rate and associated bank angle

4. Configuration Scheduling

5. Work load required

RECOMMENDATIONS

It is Recommended That:

1. The simulator tasks defined for the evaluation of the curved path approach should be designed to fit the angles, vertical distances and lateral patterns to be expected in the assumed RNAV Route and approaches between Boston and Manhattan. They should be oriented such that the headings, altitudes and airspeeds could be flown at Crows Landing by the test airplanes.

2. The actual geometry of the pattern should be initially drawn to reflect the best performance of the test airplanes and then modified to suit operational reality with respect to bank angles, descent rates, etc., as determined by the simulation.

3. The development of the operational procedures for flying the transistions from the RNAV cruise flight to the curved approach paths be concurrent with the design of the simulator experimental curved paths.

APPENDIX A

Curved Path Approaches

New York, La Guardia RW 13

Dallas - Ft. Worth RW 35

Phoenix RW 8

Los Angeles RW 25

Seattle RW 16

Minn. - St. Paul 494 RW 4

Minn. - St. Paul Braemar RW 11

Minn. - St. Paul Downtown RW 11

Hong Kong RW 13

Aspen RW 15

Juneau RW 8

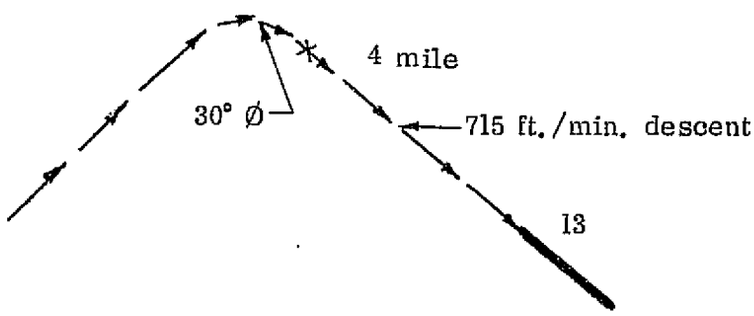
New York, La Guardia RW 13

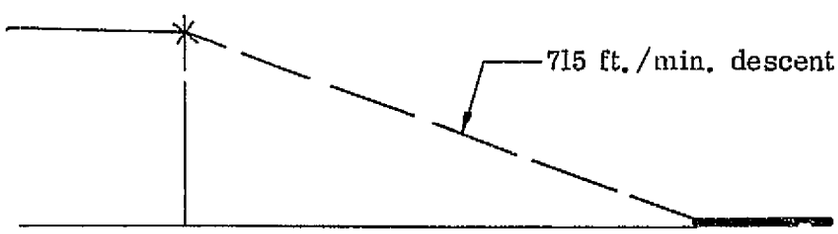
New York, Kennedy RW 12

Washington National RW 18

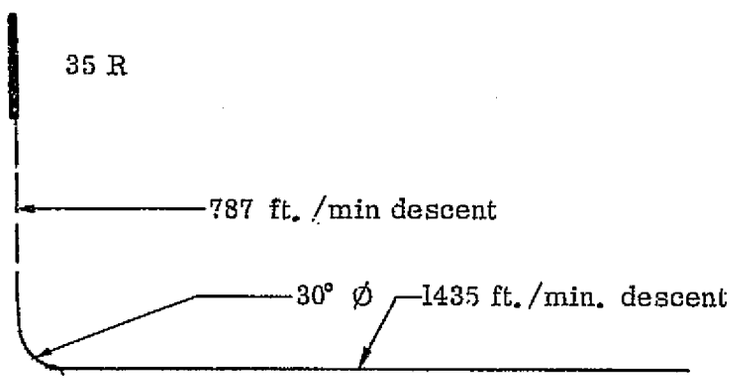
NEW YORK, LA GUARDIA
River Approach Rwy 13

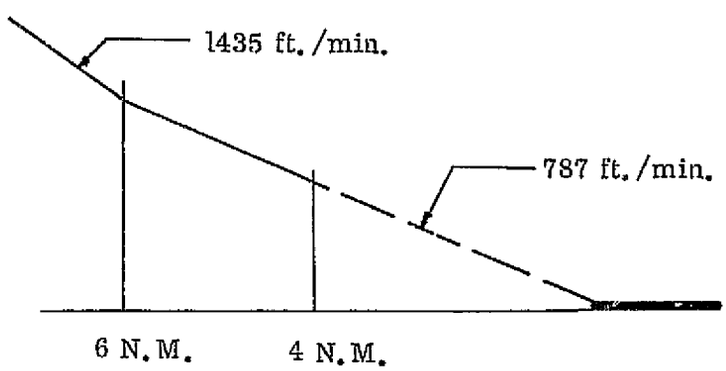
This is a Noise-Abatement approach used when weather conditions permit (3200 ft. ceiling and 5 miles visibility). The ground path is over the Hudson River with a 90 degree turn in on the IGDI ILS to Runway 13 north of Central Park. Under visual conditions the 90 degree turn using a 30 degree bank is routine with about all sizes of airplanes. The ILS guidance is very helpful and is used. The airplanes usually do not start down until after completing the final turn.





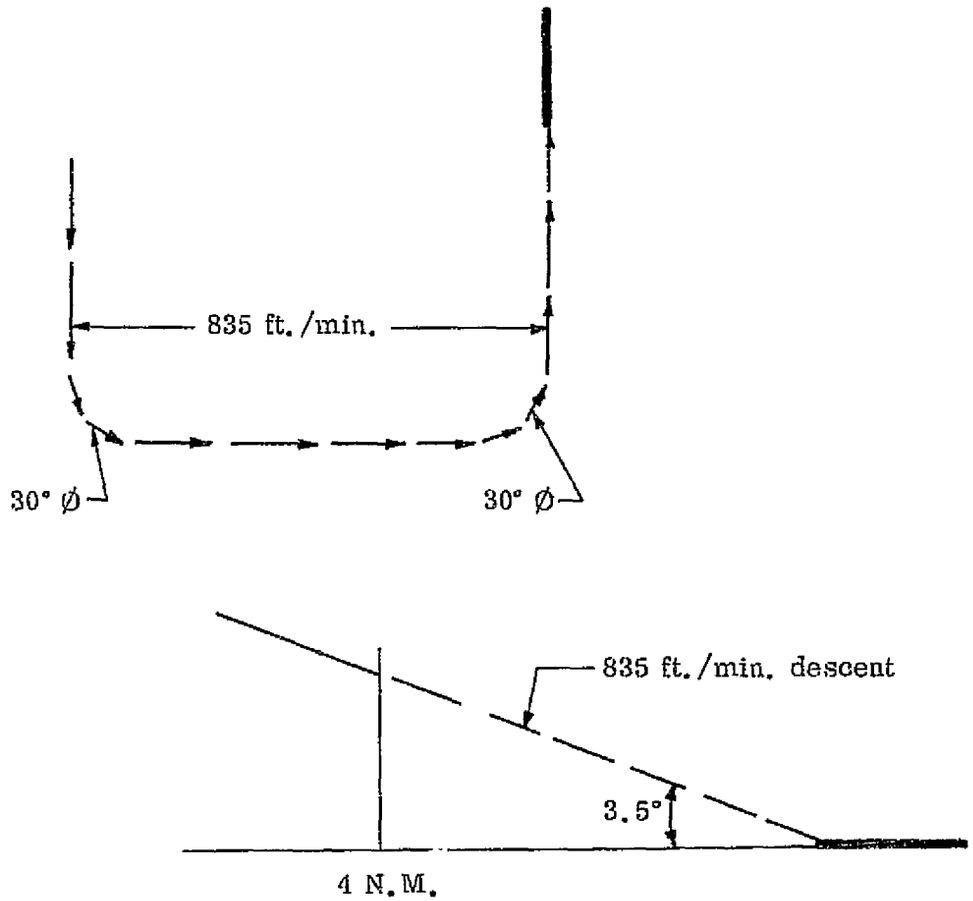
This is a Noise-Abatement approach used with good ceiling and visibility. The turn in to RW-35 is started at 3000 ft. approximately 5 miles from the runway threshold. The descent is about 6 degrees at this point. The flight path shallows out at about 2 miles and is just a little steeper than a standard 3 degree path from here to the treshold. This profile is similar to the two-segment approach vertical profile. There is the 30 degree turn during the upper segment which does not present any problem to the pilot. This approach is easy to fly.



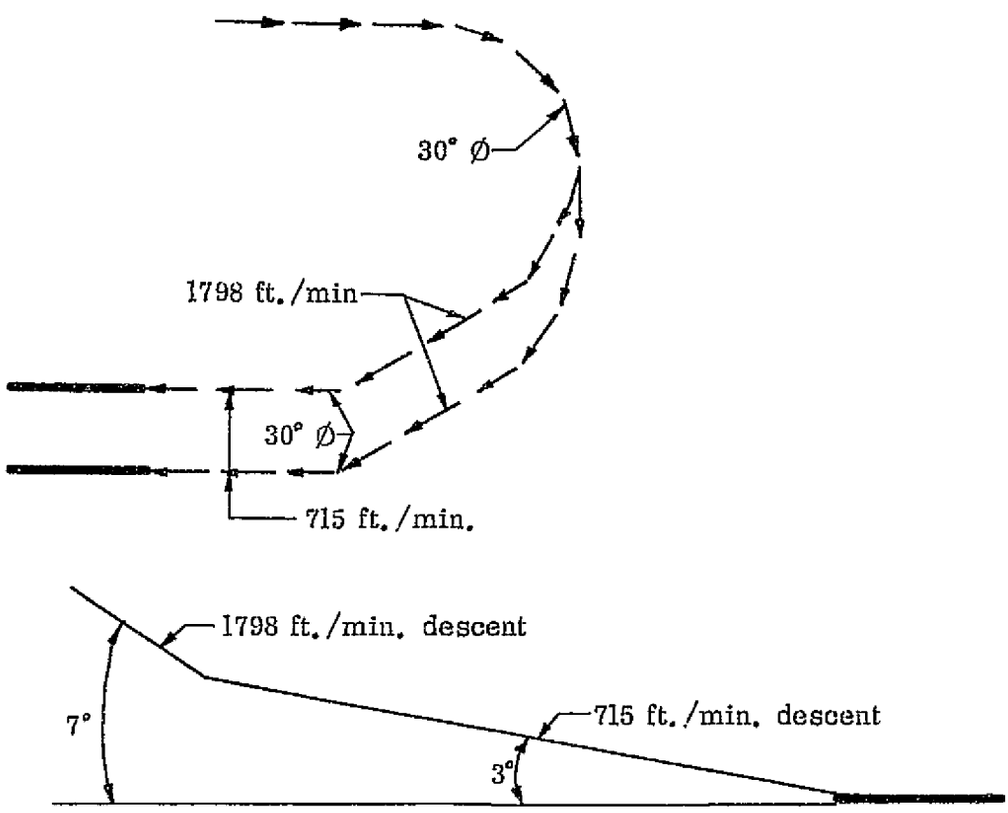


PHOENIX, ARIZONA
Black Canyon RWY 8

This is a Noise-Abatement visual approach that is used most of the time. It is a constant descent approach that is just a little steeper than a standard approach. The 3.5 degree descent path with two 90 degree turns does not present any problem to the pilot.



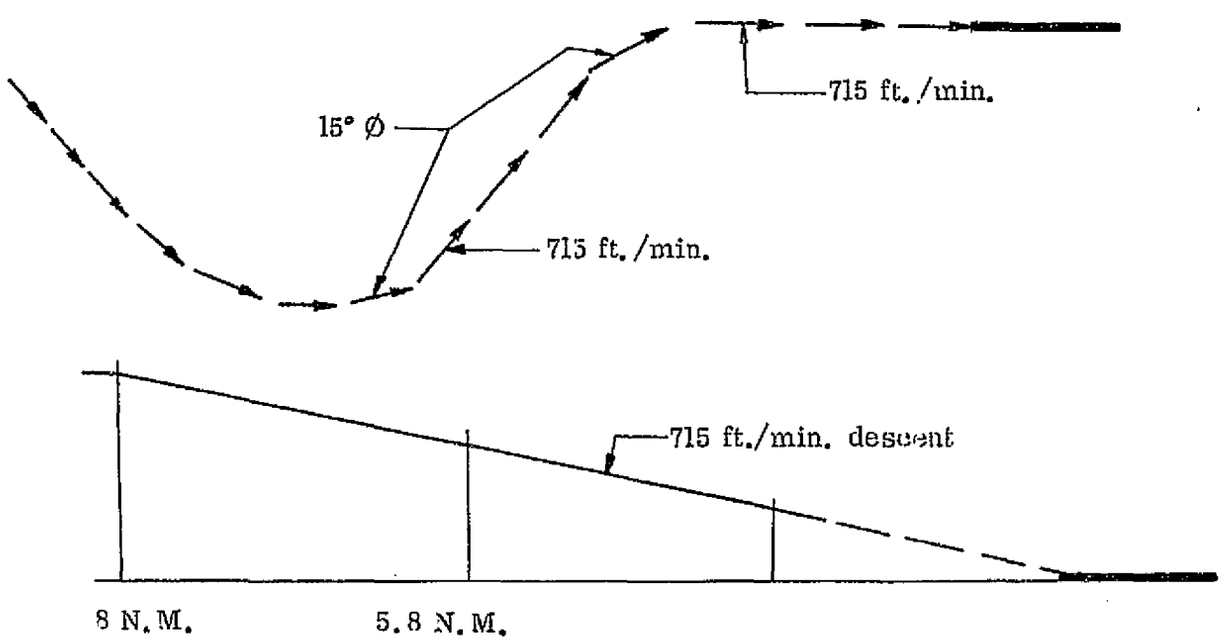
This is the routine approach flown by most traffic entering from the northwest. The turn from downwind as well as the final turn is visual. The turn is flown in two sections. A 30 degree bank descending path to establish a 45 degree intercept to final approach. The second 30 degree bank is conducted so that the airplane is on runway extended center line about 4 miles out at 2500 ft.. This produces a steep 5.6 degree flight path to the threshold. To avoid this the pilot usually continues on a steep 7 degree path to about 2 miles and then shallows to a standard approach angle. There is usually traffic coming straight in from which pilot must maintain visual seperation and on occasion this will complicate the curved approach. The distances and altitudes are great enough to allow for wide variations in flight path and thus this approach is easy to fly.



A-5

SEATTLE, WASHINGTON
Visual Bay Approach RWY 16

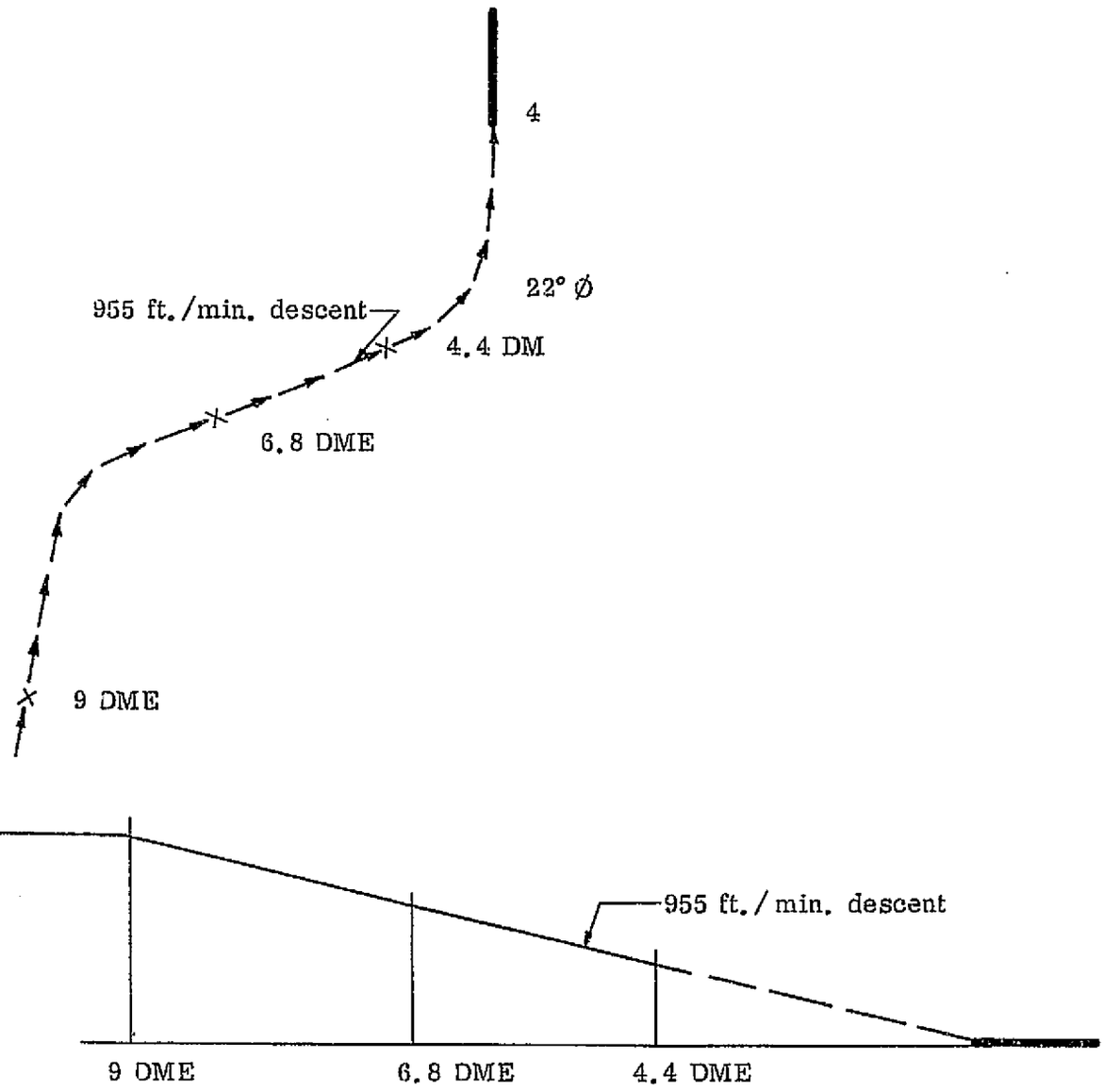
This approach is the visual noise abatement approach that is used when the ceiling is above 3500 ft.. The path is an easy transit of the Puget Sound with a turn in at Elliott Bay to a 45 degree intercept to final approach. The turns are wide and can be made with a 15 degree bank angle. If a late turn is started to final after the ILS localizer has started to come off the peg a 25 degree bank turn is all that is needed to complete the turn. The descent is constant at a standard 3 degrees and is very easy to fly.



A-L.

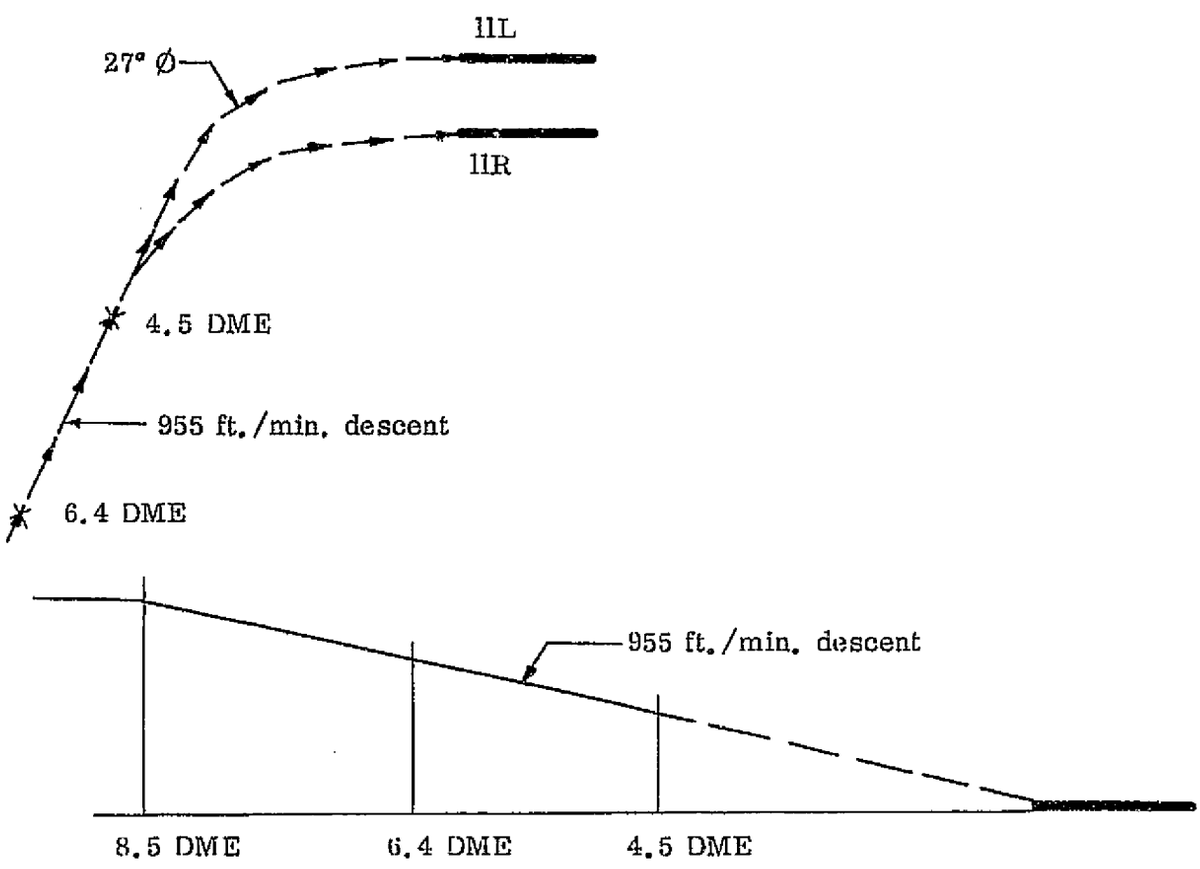
MINNEAPOLIS, ST. PAUL
494 Visual RWY 4

This was a Noise-Abatement approach designed for a short term evaluation using an approach path over a relatively unpopulated area. This approach follows Interstate Highway 494 in the Minneapolis, St. Paul area and makes a 44 degree turn onto final approach, close-in to the airport, using a 22 degree bank while maintaining a constant descent. The approach is steeper than standard and provides some close-in noise abatement by virtue of the higher altitude and lower power setting. This approach does not cause any difficulty for pilots.

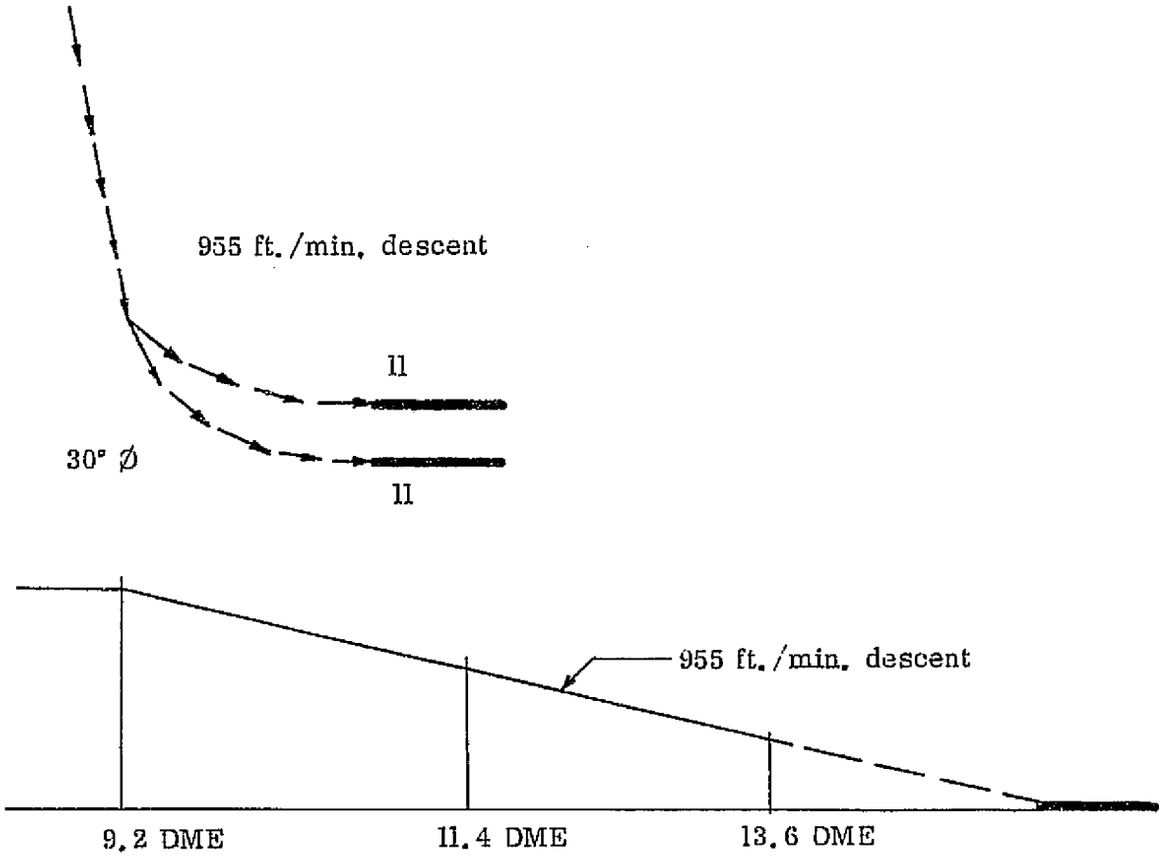


MINNEAPOLIS, ST. PAUL
Braemar RWY 11

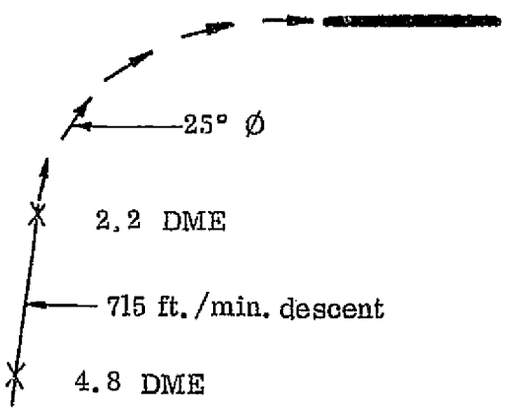
This was a Noise-Abatement approach over non-noise sensitive area. It was designed for a short term e aluation using an approach path over a relatively unpopulated area. The approach path is a straight lead in to about 2.5 miles from the airport, then a 57 degree turn to the runway, using a 2 degree bank. The descent is a constant angle once initiated and is slightly steeper than the standard 3 degrees. The steeper approach does provide some noise abatement close in. This approach does not cause any difficulty for pilots.

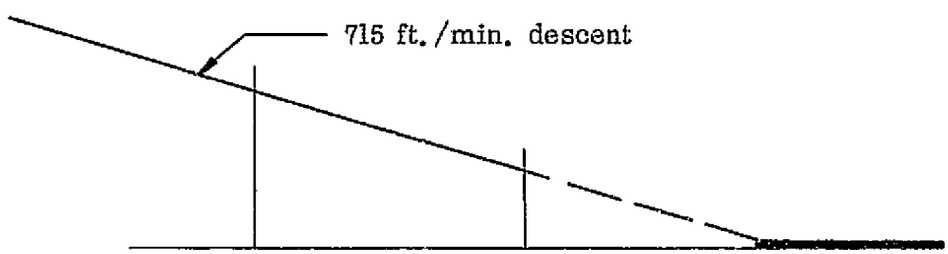


This was a Noise-Abatement approach designed for a short term evaluation using an approach path over a relatively noisey area (the downtown area). This profile kept the airplane high over the town until a constant descent could be made down to a point 2.5 miles from the runway. A 64 degree turn was made on to the final approach using about 30 degrees bank. The approach didn't cause any particular difficulty. It was noted that some pilots of large airplanes choose to fly wide on the approach so they could complete the final turn higher above the ground than would be possible when flying right on track.

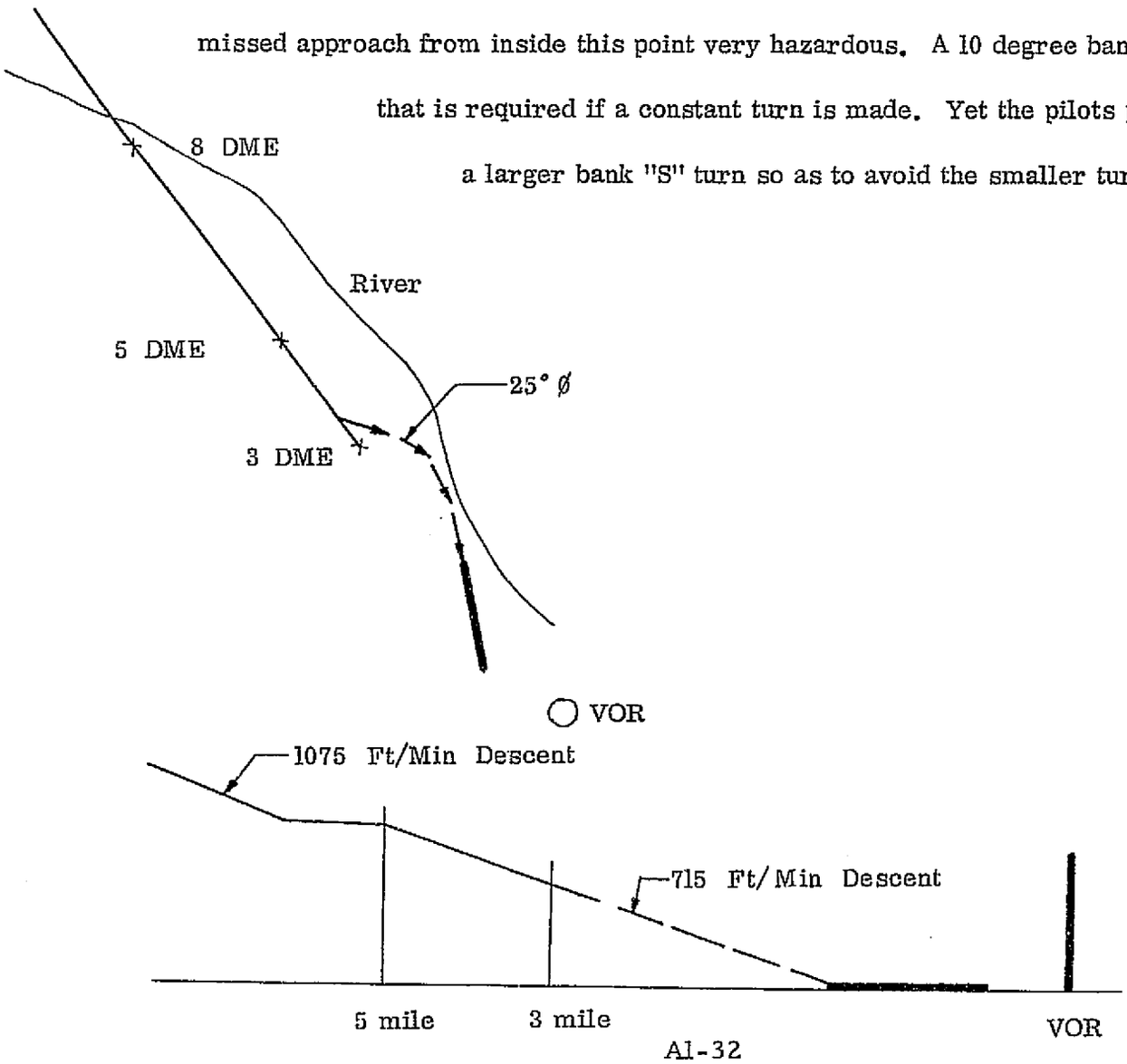


This a terrain avoidance curved approach that is difficult to fly, especially at night when the ceiling is below 1000 ft.. The final turn is made with the airplane on a standard descent ILS path of 3 degrees. This turn is 47 degrees and requires at least 25 degrees bank, and has to be completed within 1.2 miles if the airplane is to be wings level 0.5 miles from threshold. Large airplanes have a very difficult time with this approach. Lead in lights are available to aid the turn but no vertical guidance is available.

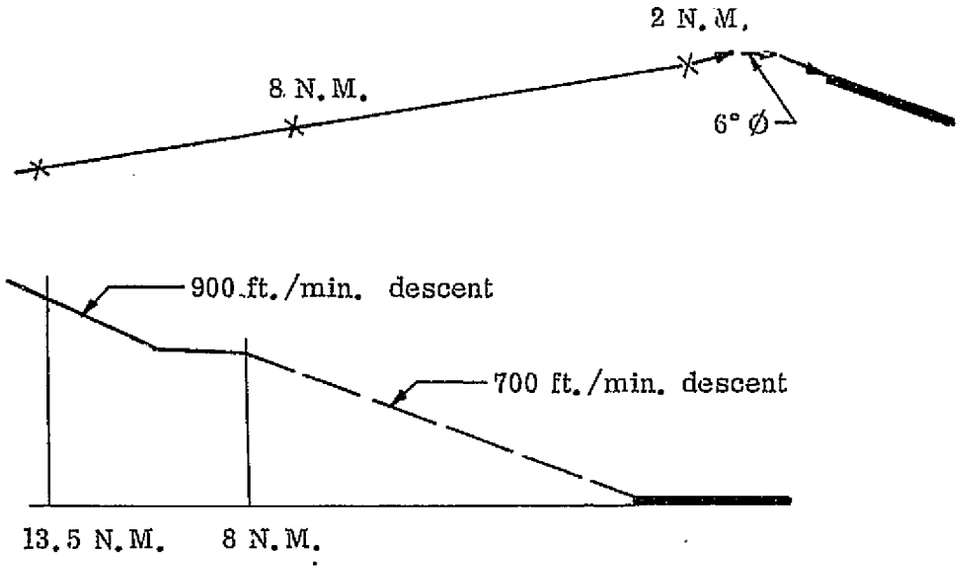




This is a terrain avoidance approach into a high altitude airport. It is not extremely diffucult with an airplane of the Convair 580 type. Most pilots flying this approach will depart the 311 degree radial at the 8 mile DME and them follow the river basin to the runway threshold. With less desirable visibility the pilots stay on the radial longer, establish the landing configuration, then when at about 3 miles out from the runway turn left to the river and them bank right to get aligned with the runway and avoid a low turn. The pilots like to stabilize the 0.5 mile or greater out from the runway because the rapidly rising terrain beyond the runway makes a missed approach from inside this point very hazardous. A 10 degree bank is all that is required if a constant turn is made. Yet the pilots prefer a larger bank "S" turn so as to avoid the smaller turn close in.



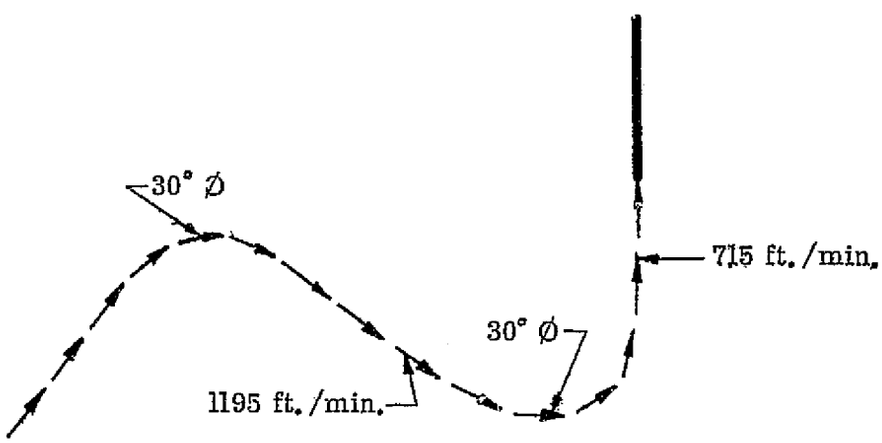
This is a terrain avoidance approach that is relatively easy to fly. The final turn is just 14 degrees and can easily be accomplished with a 6 degree bank and have the airplane wings level 0.75 miles from the threshold. The descent is slightly less than standard and does not produce any particular difficulty for the pilot

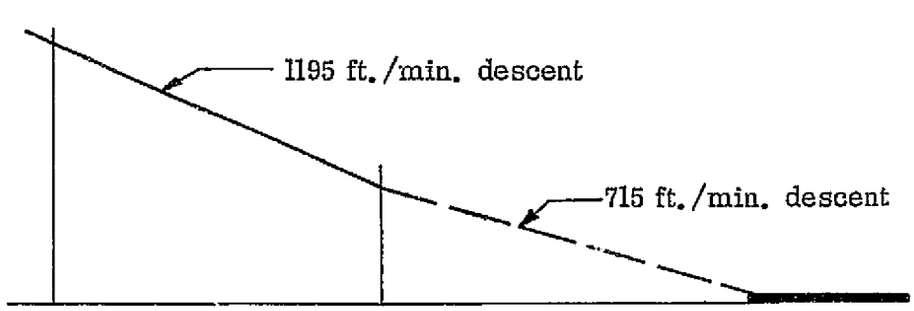


A-12

NEW YORK, LA GUARDIA
Expressway RWY 13

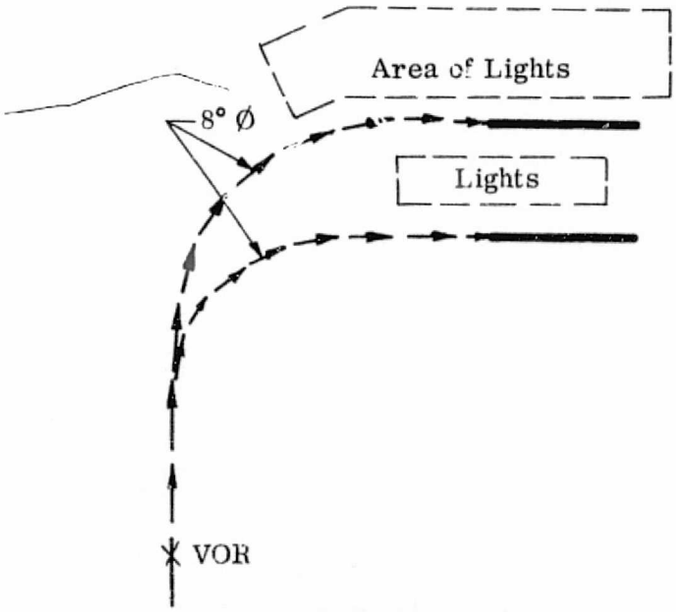
This is a Noise-Abatement approach that is used during good weather conditions. The airplane approaches over a relatively clear area to within 5 miles of the airport, it then makes a descending turn to follow the long Island Expressway until a turn of 129 degrees is needed to align the airplane with the runway. During the final turn the descent is shallowed out for the final approach. This large turn using 30 degree bank while changing pitch attitude is difficult with any airplane. It is desirable to have the airplane wings level 0.5 miles out. Some DC-9, B-737, and B-727 airplanes have to be observed still in a slight turn while crossing the threshold. This is a very difficult approach and large airplanes do not attempt it.

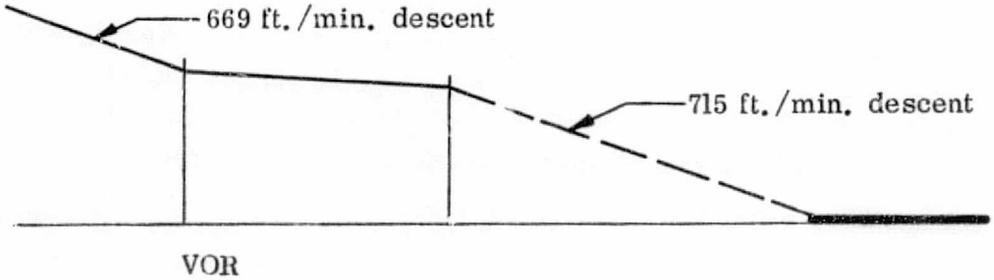




NEW YORK, KENNEDY
VOR RW 13 L/R

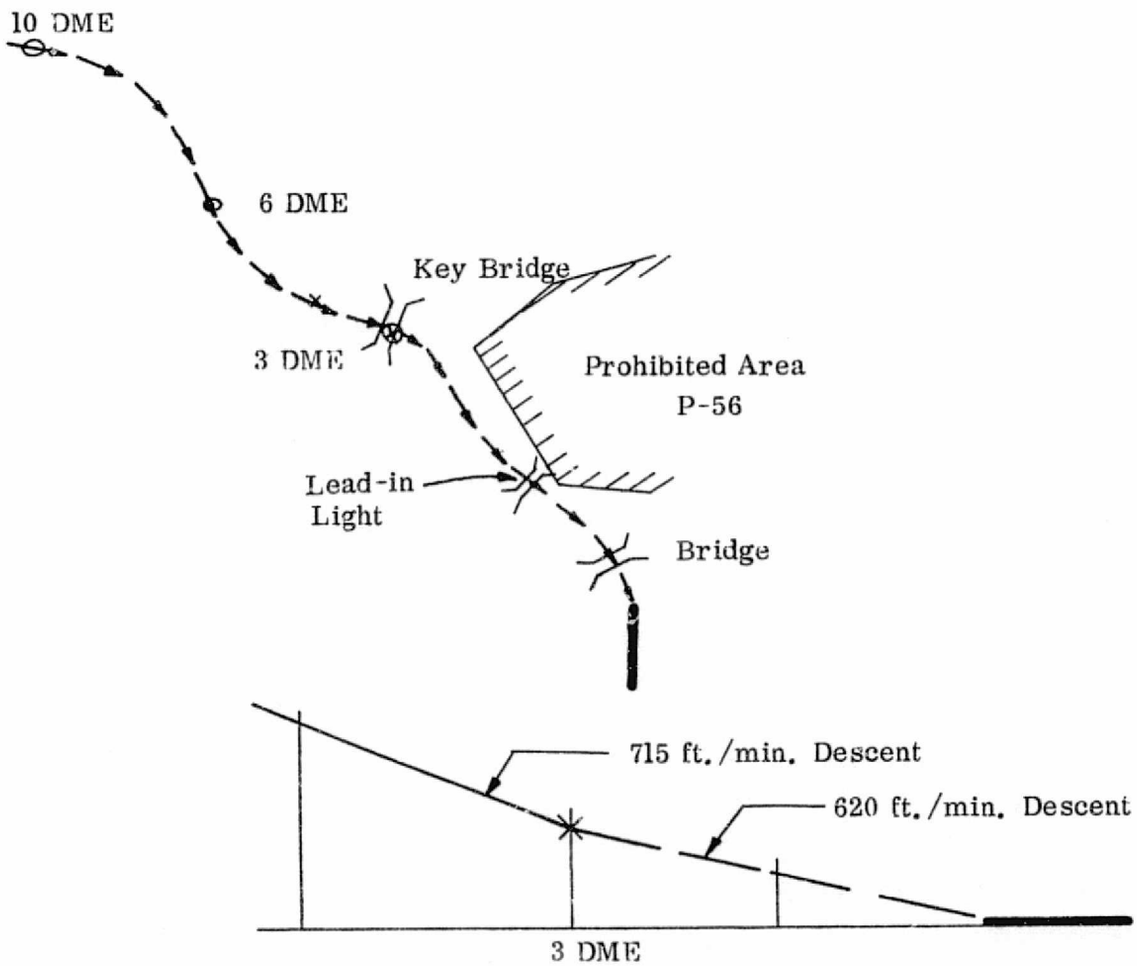
This is a Noise-Abatement approach that appears simple in theory but under some actual operating conditions becomes very difficult. The approach is straight in to the VOR at an easy descent angle after crossing the VOR a right descending turn of 90 degrees, requiring about an 8 degree bank angle, is made to align the airplane with the runway. Airplanes of all sizes fly the approach and the larger airplanes have a more difficult time. Because of the noise sensitive area the approach is made when the weather is low (1500 ft. ceiling and 4 to 5 miles visibility). At night, after it has been raining with these conditions the approach to 13 left becomes a real problem. The lead-in sequence lights are visible but the runway approach and threshold lighting is merged in a maze of area lights and reflections. This loss of reference makes the descent difficult to judge. The B-747 airplane has the most difficulty and the pilots of this airplane usually fly to the left of the sequence lights until the runway perspective is good enough for alignment without getting to close in. The lack of vertical guidance is enough of a problem that even though the turn is not difficult, airplanes end up high on final and are diving in or still turning when passing over the runway threshold. Many pilots who have flown this approach under these conditions are of the opinion that it is dangerous.





WASHINGTON, D. C.
River Approach RWY 18

This is a Noise-Abatement and a prohibited area avoidance approach. It is the most difficult of all curved approaches to fly under all conditions. When the ceiling is 3500 ft. or better the airplane follows the Potomac river all the way from 10 miles DME to the threshold. The descent is easy to make, but the pilot must pay close attention to his ground track in order to stay over the river. With a lower ceiling the airplane follows the ILS to 4 miles DME then makes a 10 degree bank turn to the river. At this point the approach becomes difficult regardless of which entry was made. From here three turns are required to stay over the river and out of the P-56 prohibited area. The B-727 airplane has difficulty making these turns and getting stabilized prior to runway threshold. The general solution is to stay along the east edge of the river bordering the prohibited area and then making a 5 degree bank turn back to the center of the river then 10 degree bank turn the last 20 degrees to align with the runway. This routine makes the path acceptable and reduces the chance of over shooting the last turn. Most pilots dislike the low "S" turn close in. This approach is legal with weather conditions 1100 ft. ceiling and 2 miles visibility. The last bridge on the river for reference is 1.75 miles out from the runway. Which means the airplane position for the last turn must be made without visual reference to the runway.



NASA CR-137975

November 1976

APPENDIX 2

Letter Report 2

NAS 2-9028

AVCON
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Letter Report 2

NAS 2-9028

Operational Requirements For Flight Control and Navigation Systems For Short Haul Transport Aircraft

Prepared by John A. Morrison

For

National Aeronautics & Space Administration
Ames Research Center
Moffett Field, California 94035

For the Period
January 23, 1976 through April 23, 1976

SUMMARY

The operational procedures for flying transistions in a jet STOL transport from enroute RNAV Cruise Flight to time-constrained STOL approach paths are initially established for a descending downwind leg, intercepting a 7 1/2 degree descent path which incorporates a 180 degree turn during the final approach.

The minimum turn radius is 3000 feet for satisfactory turn characteristics assuming IFR conditions.

The Autoflight system of the simulator flew the approaches using the operational procedures satisfactorily.

The wind effects were satisfactory.

The data recorded should be rearranged for easier data analysis.

A 90 degree turn in pattern should be added to the simulator experiment.

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INTRODUCTION

AVCON, Aviation Consultants Inc., submits this report in accordance with reporting requirements of contract NAS 2-9028. During the time period covered by this report, essentially two things were accomplished concurrently. First, Task 2 of the contract proposal was accomplished, i.e., Operational Procedures were developed for flying transitions in jet STOL approach paths. Focus was specifically on the "descending downwind with 180° turn to final within one mile of base" approach. Second, Initial Simulations under Task 3 of the contract proposal were flown.

The major emphasis of this work is the pilot operational view of how such a system would operate in airline service. As in Letter Report 1, conventional units for altitude, distance and airspeed are used throughout the report.

RESULTS

The operational procedures developed relate to specific approach patterns because operational procedures depend upon the physical parameters of a given approach. Study of the problem of integration of STOL traffic into CTOL airports indicates definite conflict due to the speed differential of the two classes of airplane. The STOL steep approach provides some relief. Additional relief can be gained by curving the final approach path so that runway alignment is achieved at a point one nautical mile from touchdown. Of the four approach patterns to be evaluated (Letter Report 1, 23 January 1976) for an assumed short haul transport route between Boston and Manhattan, the approach descending downwind with 180° final turn fits this criteria best. The distance between the downwind leg and the runway can be varied along with altitude so as to provide lateral and vertical separation of inbound traffic to the same runway. It would also allow flexibility in 4-D navigation as the corresponding 180° turns to final approach would increase in length as the distance between the runway and the downwind leg is increased. Figure 1 shows a sketch of this approach pattern as evolved after initial simulator runs on 4/12/76. Figure 2 shows the horizontal layout of these flight paths as flown in the simulator on 4/12/76.

The first simulator experiment was an evaluation of the lateral control and positioning for the minimum turn radius and maximum bank angle operationally acceptable. The final approach angle was 7 1/2° and not varied in this experiment. The wings level point on final approach

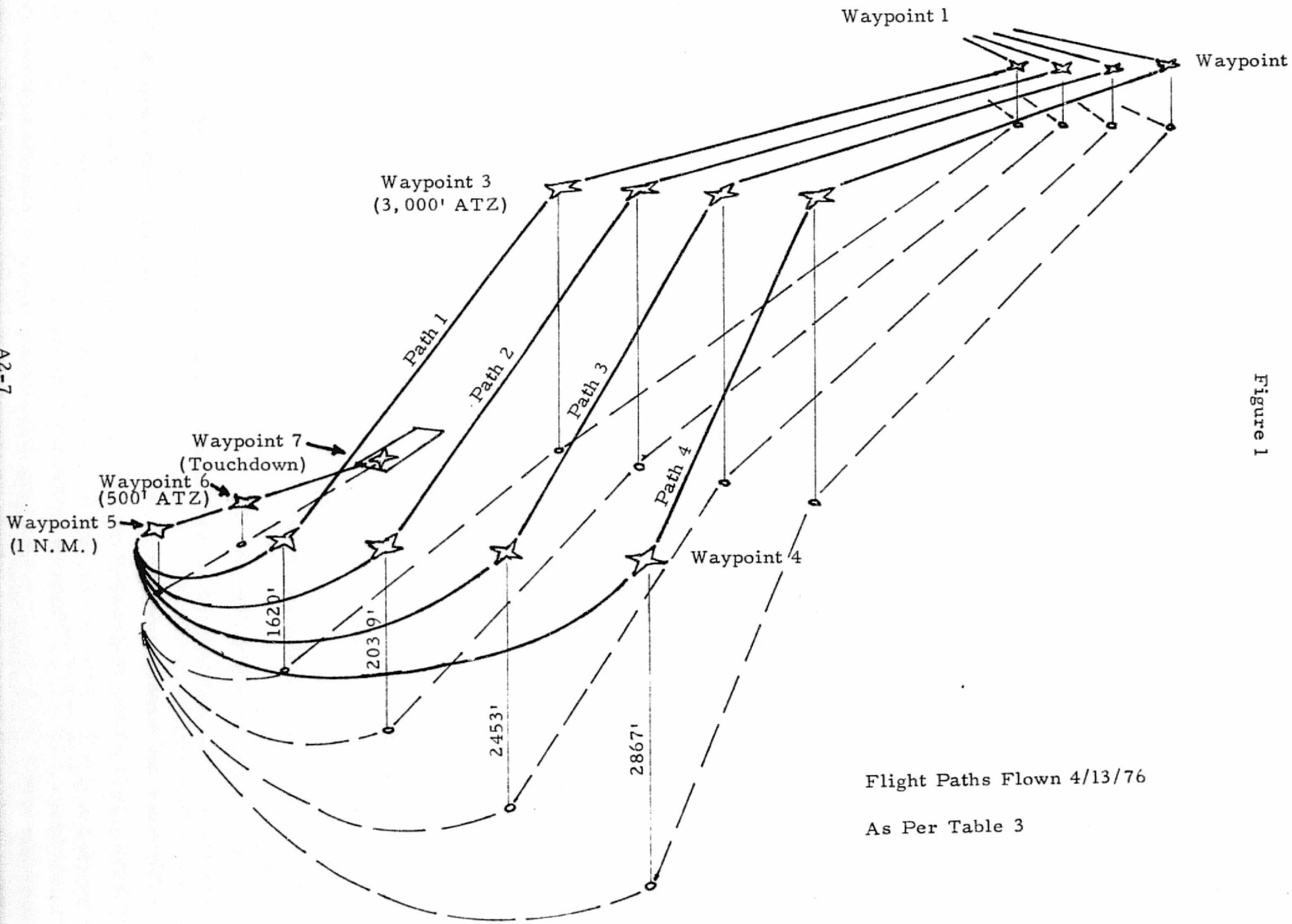
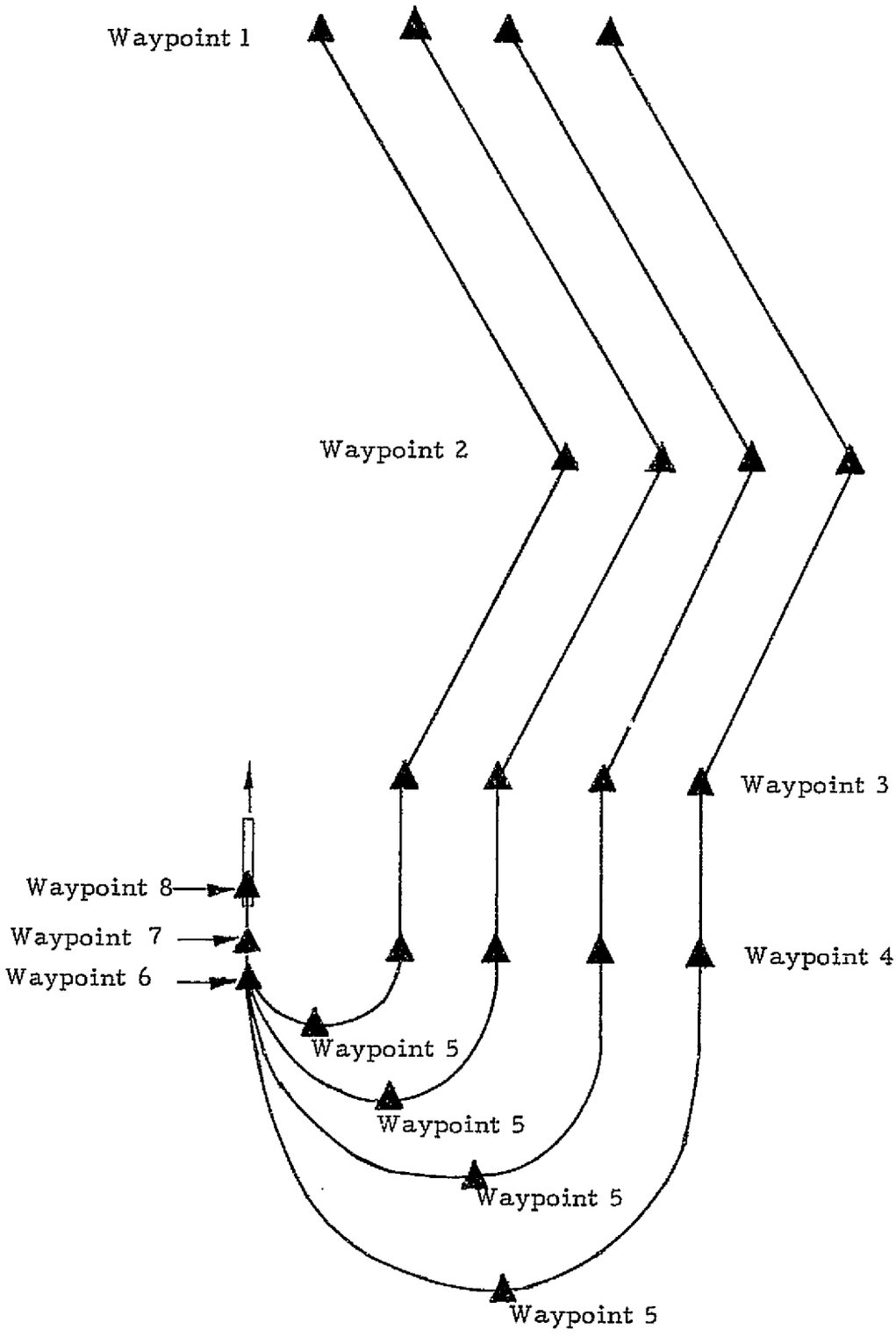

Waypoint 1
Waypoint
Waypoint 3
(3,000' ATZ)
Path 1
Path 2
Path 3
Path 4
Waypoint 7
(Touchdown)
Waypoint 6
(500' ATZ)
Waypoint 5
(1 N.M.)
Waypoint 4
1620'
2039'
2453'
2867'
Flight Paths Flown 4/13/76
As Per Table 3

Figure 1

Figure 2



Flight Paths Flown 4/12/76

was set at 1 nautical mile and not varied. The configuration was auto-flight with gear down, at the initial simulation point.

The critical point in this curved path approach appears to be the 180° turn to final approach. Under present IFR ATC procedures the last radar vector to final approach must require only a small turn to align with the ILS when cleared for approach. If the weather is 200-1/2 or less, and the final approach intercept point is within 1 nautical mile of the outer marker, that angle has to be 15° or less. If a DME arc to final approach is flown and the weather is 200-1/2 or less, that arc is usually 5 nautical miles or more outside the outer marker. The governing criteria is then the time required following the turn to become stabilized on that final approach. Thus this 180° turn must have resolved several things: First, is the guidance and precision of navigation sufficient to align the airplane on the final approach course? Second, how steep of a bank angle is possible for easy following of the final turn? And related to that, how are the roll-in and roll-out characteristics?

Operational Procedures

Operational procedures established for flying transition from enroute RNAV cruise flight to time-constrained STOL approach paths are:

First Terminal Area Waypoint

1) Approach descent check completed.

2) Airplane in maneuvering configuration.

Second Terminal Area Waypoint

1) Airplane to approach configuration.

2) Landing gear extended.

3) Autoflight or Auto Systems on.

4) Final Descent Check Completed.

Third Terminal Area Waypoint

(This waypoint equates to the standard Outer Marker of an ILS)

1) Established into time0constrained STOL approach paths.

2) IFR Flight techniques in effect from this point on.

Simulation 4/12/76

This simulation was primarily conerned with the ability to make that 180° turn from the downwind leg to the final approach. The evaluation starts on the downwind leg of the approach at Waypoint 3. (See figure 2). The path from Waypoint 3 to Waypoint 4 is flown at 1400 ft. AFL. The descent and turn starts at Waypoint 4 and continues through Waypoint 5 down to Waypoint 6 where the 7 1/2° final approach starts. The RNAV system is programmed to provide a constant radius of turn from Waypoint 4 through Waypoint 5 to Waypoint 6.

As Waypoint 4 is 1500' AFL and Waypoint 6 is 799' AFL, each of the paths have a different descent angle between Waypoints 4 and 6. Table 1 shows the turn radius and descent angles between Waypoint 4 and 6. The average bank angles of the two segments (Waypoints 4 to 5 and 5 to 6), shown are the values taken from the recorded data. It is caculated by reading the bank angle during each second as recorded.

Table 1

Path	Turn Radius	Descent Angle 4 to 6	Average Bank Angle	
			4 to 5	5 to 6
1	2000'	19.3°	12 1/2°	11°
2	3000'	12.1°	9°	7°
3	4000'	10.0°	not flown	
4	5000'	8.0°	not flown	

The bank angle versus time plot for the 180° turn (see Figure 3) of Run 1, Path 1 indicates a high roll rate initially until 15° bank is reached in about 11 seconds, then a shallow-down to 10° in about 5 seconds. This bank varied about 1 degree until Waypoint 5 was reached, then gradually increased to 11° until 45 degrees of turn remained. The bank shallowed to 8° over the next 7 seconds then rolled level in 4 seconds with one degree overshoot. The roll in rate of approximately 1 1/2° per second and the roll out rate of approximately 2° per second appear too fast and the general roll characteristics are too abrupt for good IFR conditions. An examination of Path 2, Runs 4 and 5, indicates a similar pattern. The bank angle shallows during the first quarter of the turn. There is a second peak just prior to the half way point then a smooth, nearly constant bank until rollout.

This characteristic was thought to be related to one or more of four things. 1) pitch characteristics due to the change in descent angle 2) Waypoint 5 midway through the final turn 3) the airspeed change by having programmed the speed at Waypoint 4 at initial approach speed and at Waypoint 6 to final speed 4) the MLS effect as it came into the navigational problem.

The plot of pitch versus time is shown with the bank angle charactereistics in Figure 3. Note that in each of these runs the pitch characteristics were different. Each path uses a different descent angle. Run 1 was the steepest, (descent angle approximately 6.4°) and indicated

the most pitch angle variation; the largest variation occurring during the third quarter of the turn. Run 2 was shallower (descent angle approximately 4.3°) and showed smoother pitch characteristics, but it too had some large variations in the fourth quarter of the turn. Run 5 (which had the 7 1/2° final descent angle) shows still better pitch characteristics without any large variations during the turn. At this point there appears to be no correlation between pitch and bank characteristics.

Waypoint 5 can be tested for its effect by taking it out of the simulation.

The airspeed can be tested for its effect by programming the final airspeed to start at Waypoint 4 and making the turn at a constant airspeed.

The MLS effect will require some additional study to decide upon a course of action for its evaluation.

C.2

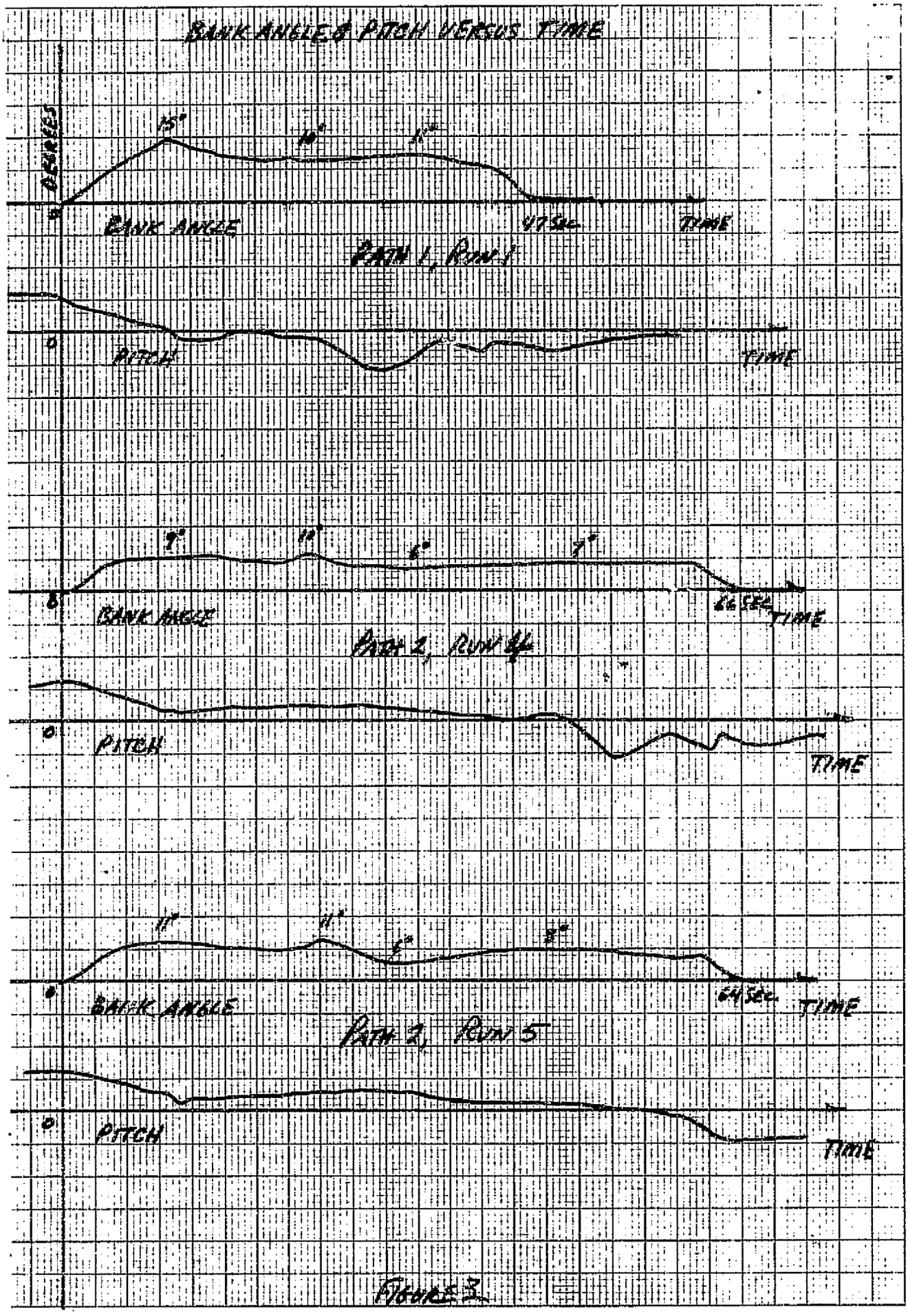

BANK ANGLE & PITCH VERSUS TIME
DEGREES
15°
10°
10°
0
BANK ANGLE
47 SEC.
TIME
PATH 1, RUN 1
0
PITCH
TIME
9°
10°
6°
7°
0
BANK ANGLE
66 SEC.
TIME
PATH 2, RUN 4
0
PITCH
TIME
11°
11°
6°
8°
0
BANK ANGLE
64 SEC.
TIME
PATH 2, RUN 5
0
PITCH
TIME

FIGURE 3

Simulation 4/13/76

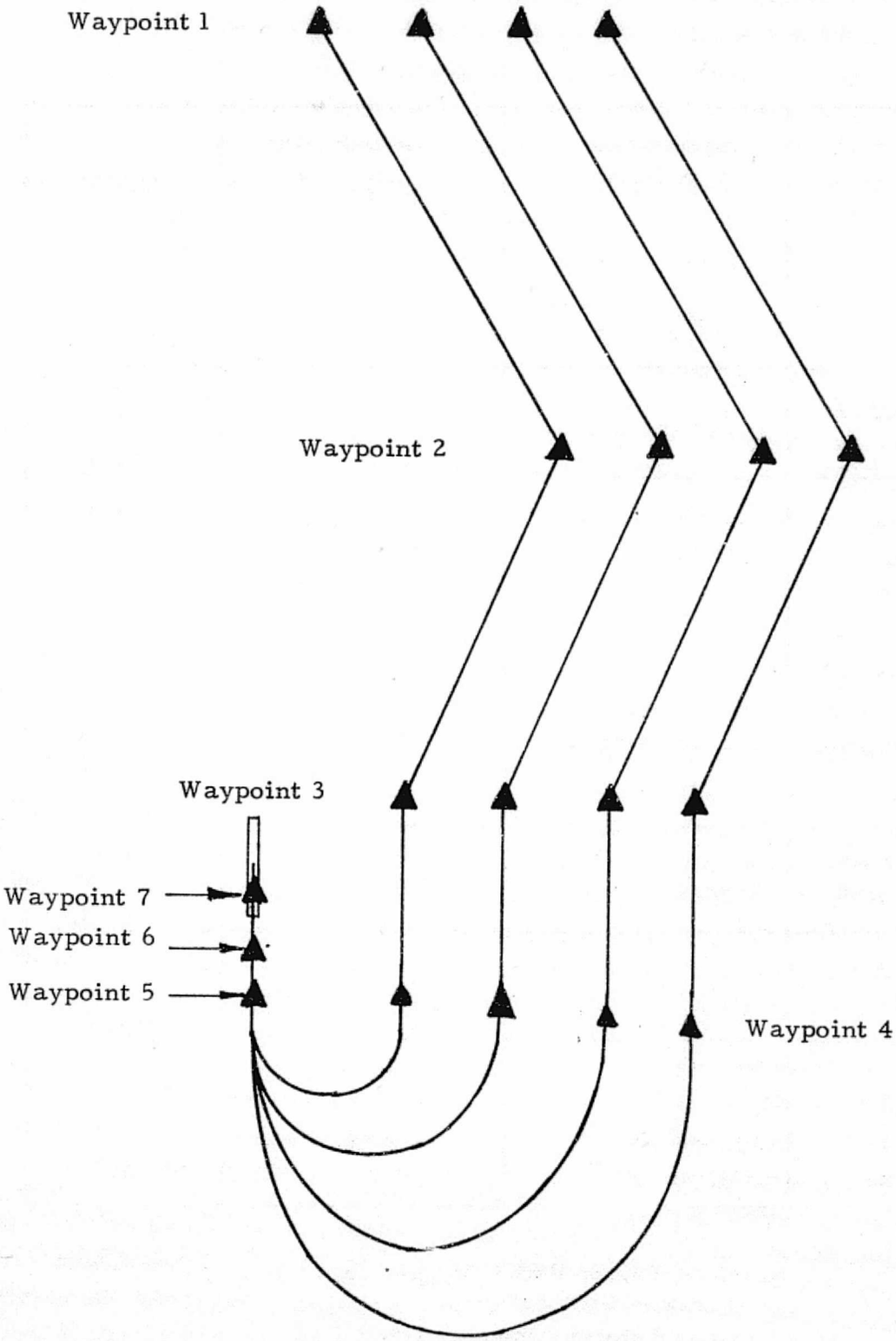
After one trial on path 1 and four trials on path 2, we decided to reprogram the approach. Waypoint 5 was eliminated as unnecessary, and the next points renumbered. Waypoint 4 was moved 5 feet south of its original position so that the programmed turn would be just under 180°. This eliminates any possible indecision in the direction the turn might be attempted. The 7 1/2° final approach path was extended throughout the curved portion of the approach to eliminate the two-segment effect on the turn. Waypoint 4 is the transition point for the approach to the final descent angle. The variable descent angle of the approach (Waypoints 3 to 4) is on the downwind leg. Figure 4 shows the horizontal layout of the revised Waypoints. Figure 1 also reflects this change. The following table shows path length and downwind descent angle.

Table 2

Path	Distance Wy 4 to Wy 6	Downwind Leg Descent Angle
1	6,283'	6.36°
2	9,424'	4.25°
3	12,566'	3.19°
4	15,708'	2.55°

Table 3, which follows, shows coordinates of waypoints on figure 4 and figure 1 after reprogramming of the approach following simulator runs on 4/12/76.

Figure 4



Flight Paths Flown 4/13/76

Table 3

PATH 1			
Waypoint	Coordinates North-South	Coordinates East-West	Altitude
7	0	0	0
6	-3798	0	500
5	-6070	0	799
4	-6075	4000	1620
3	3000	4000	3000
PATH 2			
Waypoint	Coordinates North-South	Coordinates East-West	Altitude
7	0	0	0
6	-3798	0	500
5	-6070	0	799
4	-6075	6000	2039
3	3000	6000	3000
PATH 3			
Waypoint	Coordinates North-South	Coordinates East-West	Altitude
7	0	0	0
6	-3798	0	500
5	-6070	0	799
4	-6075	8000	2453
3	3000	8000	3000
PATH 4			
Waypoint	Coordinates North-South	Coordinates East-West	Altitude
7	0	0	0
6	-3798	0	500
5	-6070	0	799
4	-6075	10000	2867
3	3000	10000	3000

Flight Paths flown 4/13/76

Refer to Figures 1 and 4

Examination of the bank angle time history of each of the four paths indicates one characteristic similar to the initial simulator runs on 4/12/76. (See figure 4). The airplane has a tendency to over-bank on the initial roll into the turn. The bank angle then shallows out until about half way through the final turn when another peak is reached. The turn then steadies out to approximately the theoretical bank required for the turn radius and airspeed. The bank characteristics of the first half of these turns is unsatisfactory in performance, yet bank characteristics of the second half are very satisfactory. The Waypoint midway in the final turn is not in this simulation, therefore suffers no blame. The airspeed is essentially constant and also bears no blame. The use of the MLS for position calculations may account for the change in bank characteristics during the turn. This possibility should be studied further.

Table 4 summarizes the characteristics of the second approach path experiment.

Table 4

Path/Run	Length Feet	Time Seconds	Average Airspeed Knots	Bank Angles, degrees		
				Theory	Actually Used	
					Average	Maximum
1-1	6,283	49	75.9	14.3	17.7	28.0
2-2	9,425	71	78.4	10.3	11.2	18.0
3-3	12,566	95	78.4	7.7	8.4	14.0
4-4	15,708	118	78.9	6.3	6.5	12.0

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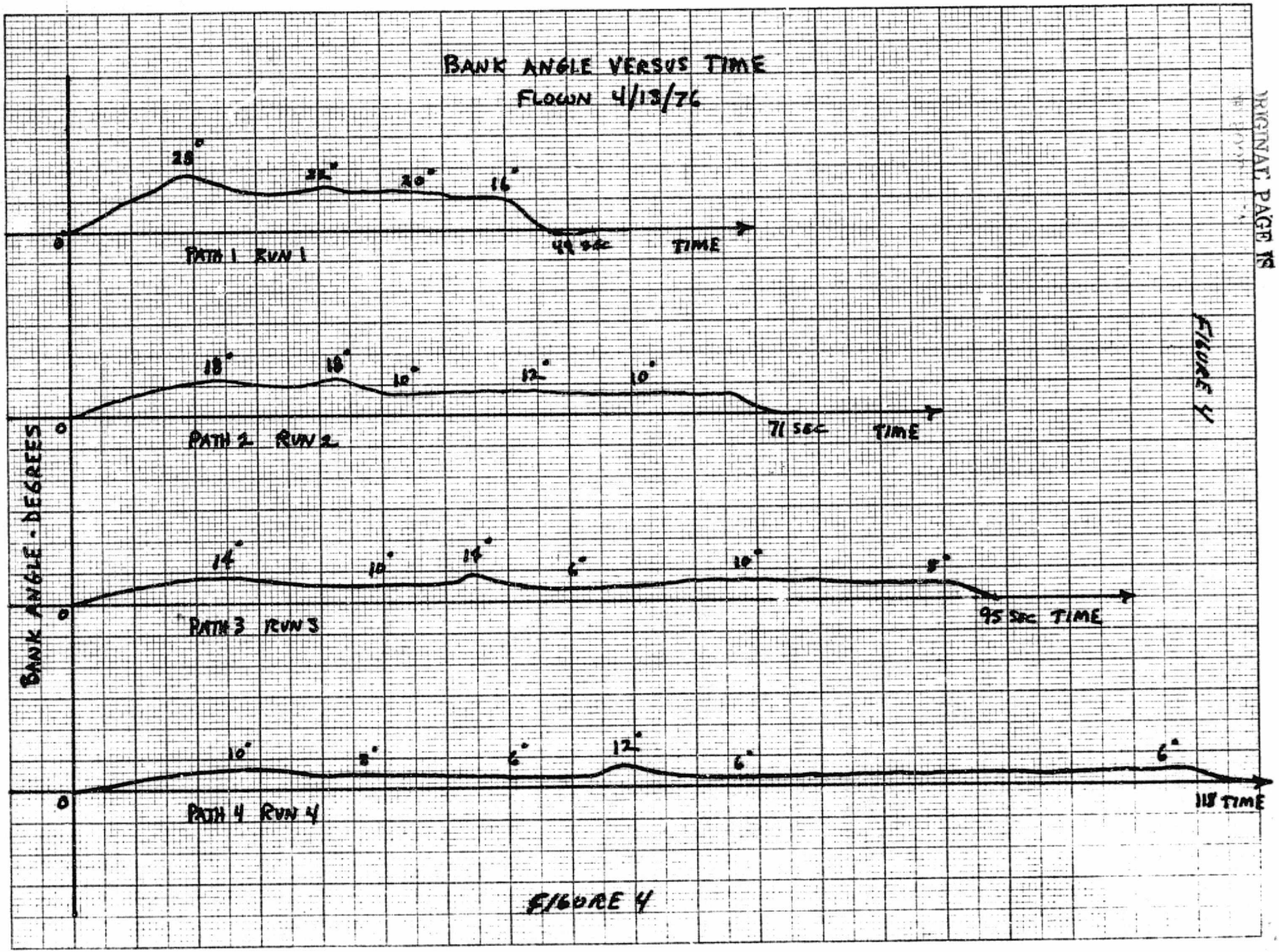

FIGURE 4

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The magnitude of the bank angle required for the 2,000' radius of Path 1 is too high for good IFR operations. The theoretical bank required is 14.3°. If the variation in bank did not exceed ± 5°, then the bank could be about 20° which is a bit too steep for good handling qualities for the 180° turn to final. The turns of 3,000' radius and larger have good handling qualities. The last half of Path 2 indicates about 10° as the steady bank angle with 12° as the maximum. The roll out on final from the turn of Path 2 and subsequent Paths was very satisfactory.

Table 5 summarizes the characteristics of Path 2 generally on the second experiment.

Table 5

Path/Run	Length Feet	Time Seconds	Avg Air Speed Knots	Bank Angle(degrees)		
				Theory	Actual Used	
					Avg	Max
2 - 5	9,425	73	76.5	9.8	11.7	16
1 - 10	6,283	50	74.3	13.7	19.0	30
2 - 11	9,425	101	93.3	5.2	8.8	26
2 - 12	9,425	74	75.5	9.5	12.4	24
2 - 13	9,425	89	62.6	6.6	9.7	20

Refer to Figure 7

On Run 5, Path 2, the change-over from RNAV to MLS occured at the 1 mile waypoint (5) rather than waypoint 6 (500' above touchdown). The average airspeed was slightly lower and the time and bank angle

correspondingly changed. Other than that, there doesn't appear to be any change in the turn qualities. (See Figure 5).

Path 1 was evaluated with a wind. Run 10 had a 20 knot tail wind on the downwind leg and a 20 knot headwind on final approach. The flight path characteristics on this run were not good. The high ground speed requires a larger bank angle to follow the Path and the magnitude of that angle makes the turn qualities unsatisfactory. The 30° maximum bank and the 17° bank prior to roll out on final approach are both unsatisfactory.

Path 2 shows much better turn qualities with respect to wind. Run 11 had a 40 knot tail wind on the downwind leg and a corresponding 40 knot headwind on final approach. This plot shows the characteristics expected due to this type wind. The first half of the turn is dramatically different from the last half. If the final turn is considered in two separate parts, the first 90° of turn is traversed in 30 seconds at an average ground speed of 157 knots. This would require 36° of bank if the turn were constant. It actually required a maximum of 26°. The last 90° of turn is completed in 71 seconds averaging 39 knots which would require 2.5° of bank if the turn were constant. It actually required a maximum of 3°. The constantly changing wind effect causes a peculiar but acceptable turn quality. The high bank angle is required only during the first part of the turn, then the bank shallows down to a very small value and is satisfactory. The average ground speed on final approach was 30 knots and the bank angle onto final was so small that the sense of turning through the last 15° was negligible.

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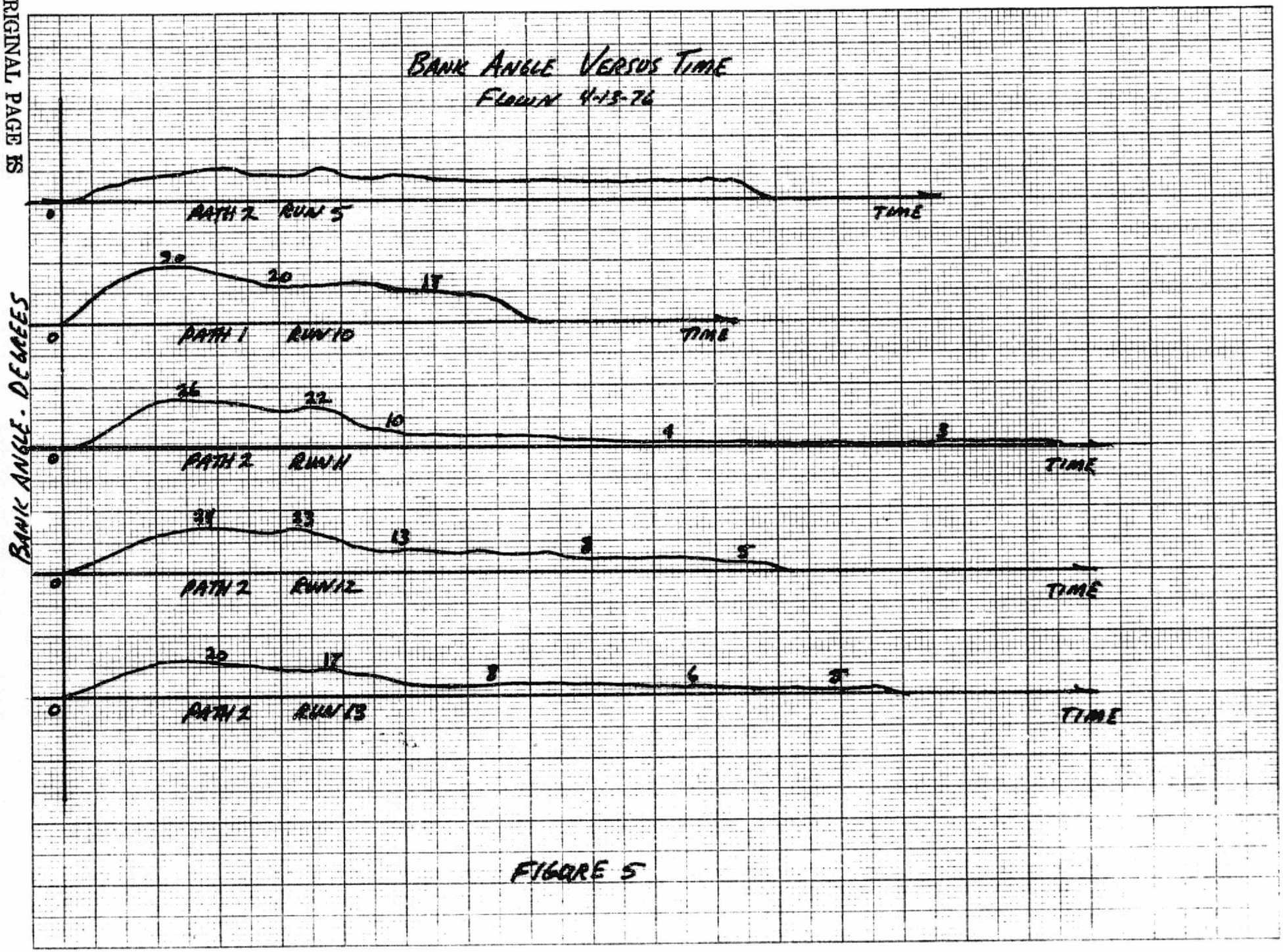

FIGURE 5

The crosswind characteristics of Path 2 are also very good. Run 12 has a 20 knot wind from 023°. This is a 30° left crosswind on the downwind leg and a 30° right crosswind on final. The final half of this turn is acceptable because of the way in which the last half eases into a gentle turn to final. The crosswind did not appreciably change the turn qualities.

Run 13 has a 20 knot wind from 323° which reverses the side from which the wind comes. The turn qualities are still very satisfactory. The path time is stretched out more and the first half of the turn doesn't go beyond 20° bank angle.

Further attempts at wind evaluation were tried by changing the wind velocity of the wind direction as in a wind shear. These were inconclusive due to the way that the wind is changed in the simulation.

CONCLUSIONS

1. The bank characteristics of Path 1 (2000' turn radius) are unsatisfactory for IFR conditions.

2. The bank characteristics of Paths 2, 3, and 4 are satisfactory for IFR conditions.

3. The roll in characteristics of Paths 2, 3, and 4 are acceptable.

4. The roll out characteristics of Paths 2, 3, and 4 are satisfactory.

5. The autoflight system flew the approaches adequately but the precision of the navigation is unknown.

6. The effect of wind on Paths 2, 3, and 4 is satisfactory.

RECOMMENDATIONS

1. Program the strip recorder to place the following parameters close together -

    1. Bank Angle
    2. Roll Rate
    3. Pitch Angle
    4. Pitch Rate
    5. Cross Track Deviation
    6. Vertical Path Deviation
    7. Airspeed
    8. Waypoint Ennunciation
    9. Wind Velocity
    10. Wind Direction
    11. Turbulance, Vertical
    12. Turbulance, Longitudinal

2. Examine flight Paths 2, 3, and 4 for precision with wind and turbulance.

3. Evaluate Manual Flight.

4. Vary the angle of the MLS signal and evaluate the effect it has on bank characteristics.

5. Program a 90° turn to final flight Path with variations in the distance from touchdown at which the turn is complete.

6. Continue the simulator experiment for further refinement of the approach paths and procedures.

7. Continue to analyze the accumlated data.

NASA CR-137075

November 1976

APPENDIX 3

Reference Flight Paths

Wind Variations RFP 3

Waypoint Data and Variations Between Waypoints RFP 6, 7, 8

Contents of Appendix 3

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Table A3-1 Wind Variations RFP 3 8/4/76 Times and Bank angles produced by variations in test winds. calm, 323 /40 kts, 023 /40 kts.	A3-13
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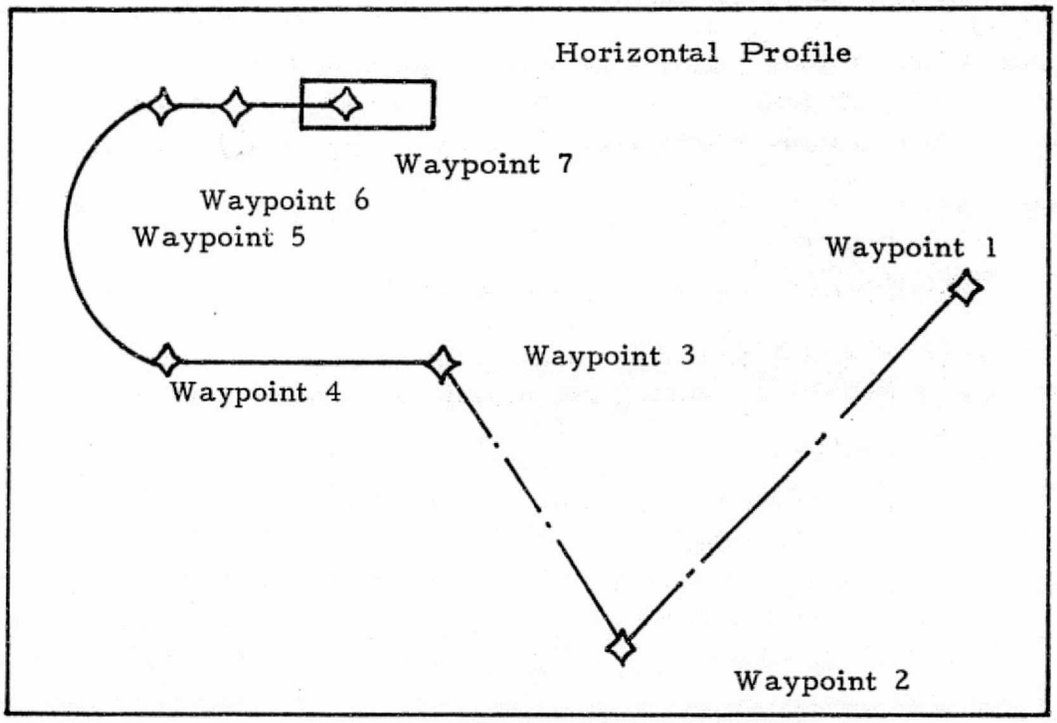
Reference Flight Path 1

Way-point	Coordinates			Flight Distance Fm Wpt 7
	x	y	z	
1	30,300	5,400	3,000	52,762
2	13,425	12,075	2,175	34,615
3	3,000	4,000	1,625	21,428
4	-6,075	4,000	1,625	12,353
5	-6,070	0	799	6,070
6	-3,798	0	500	3,798
7	0	0	0	0



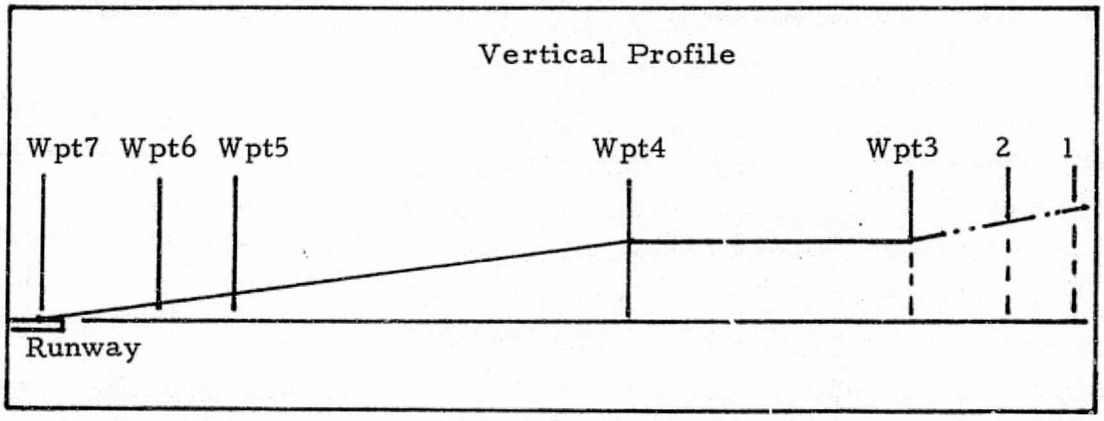
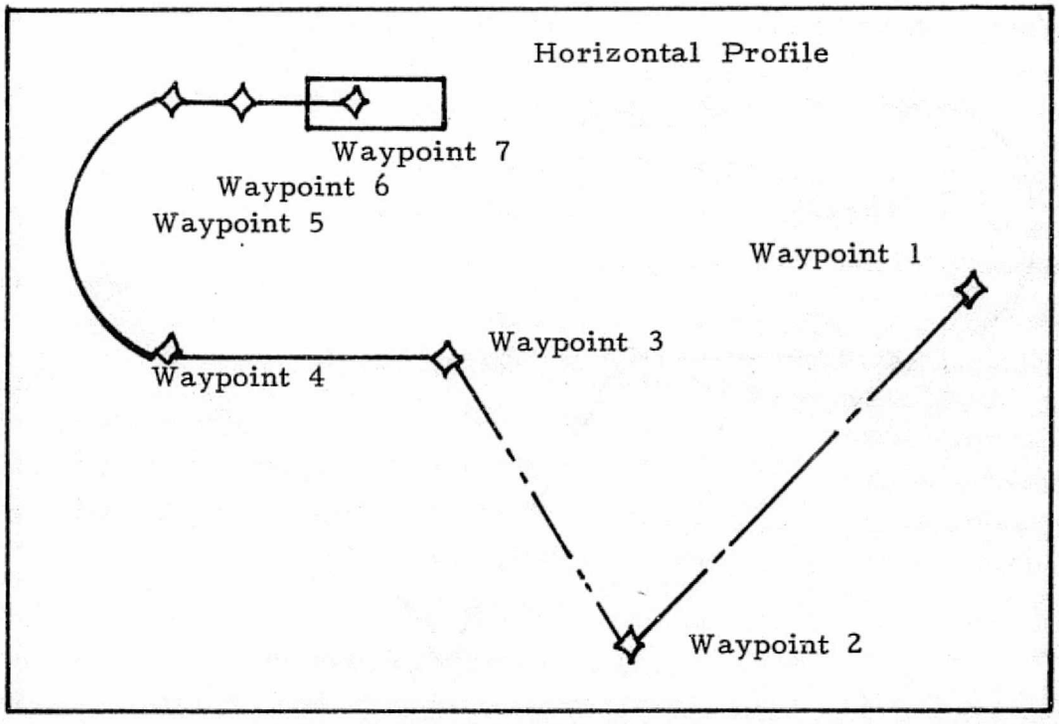


Figure A3-1

Reference Flight Path 2

Way-point	Coordinates			Flight Distance Fm Wpt 7
	x	y	z	
1	30,300	7,400	3,000	55,904
2	13,425	14,075	2,425	37,757
3	3,000	6,000	2,039	24,570
4	-6,075	6,000	2,039	15,495
5	-6,070	0	799	6,070
6	-3,798	0	500	3,798
7	0	0	0	0



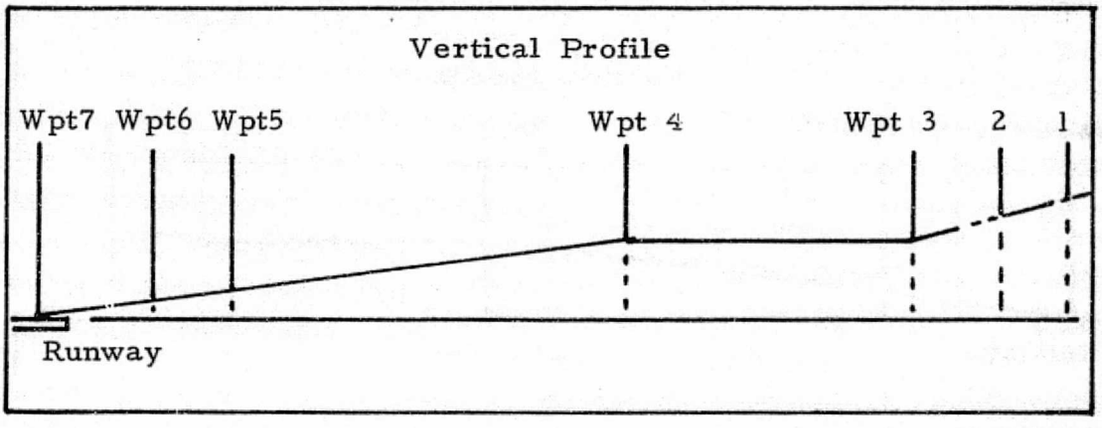
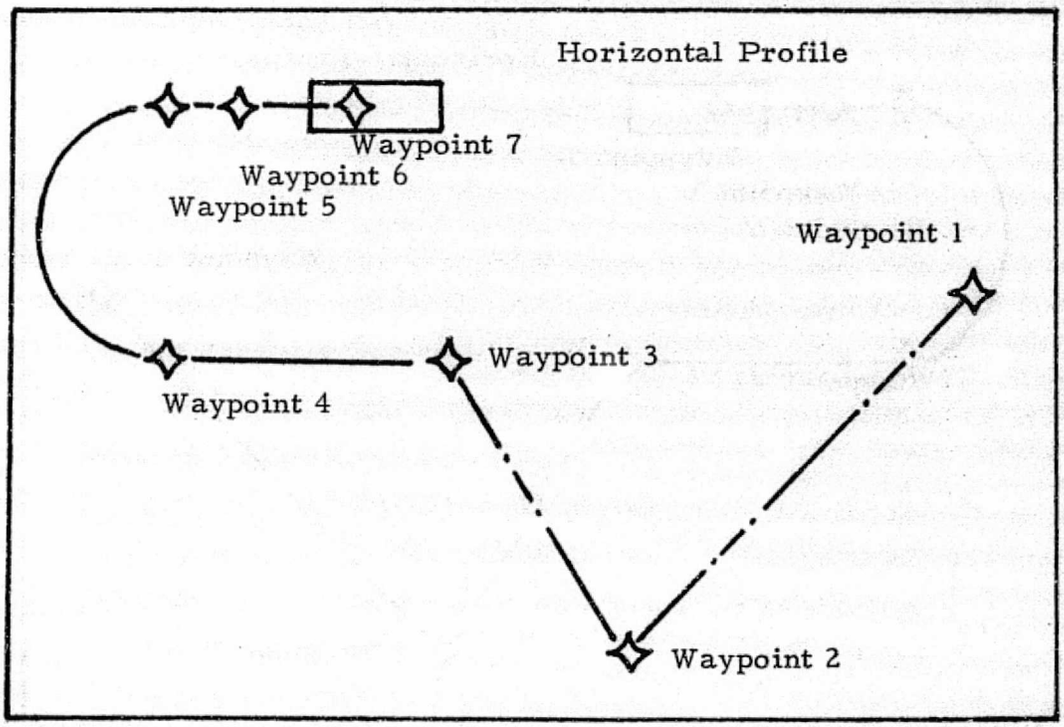


Figure A3-2

Reference Flight Path 3

Way-point	Coordinates			Flight Distance Fm Wpt 7
	x	y	z	
1	30,300	9,400	3,000	59,045
2	13,425	16,075	2,672	40,898
3	3,000	8,000	2,453	27,711
4	- 6,075	8,000	2,453	18,636
5	- 6,070	0	799	6,070
6	- 3,798	0	500	3,798
7	0	0	0	0



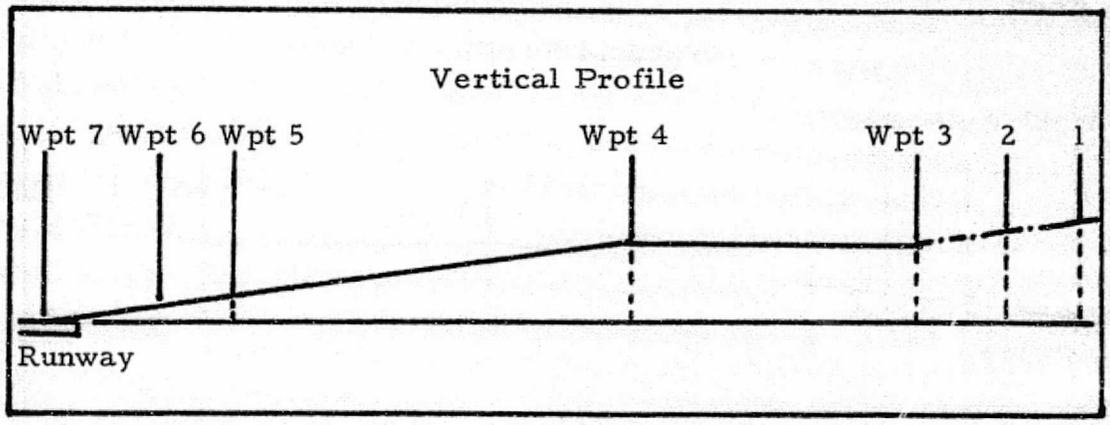
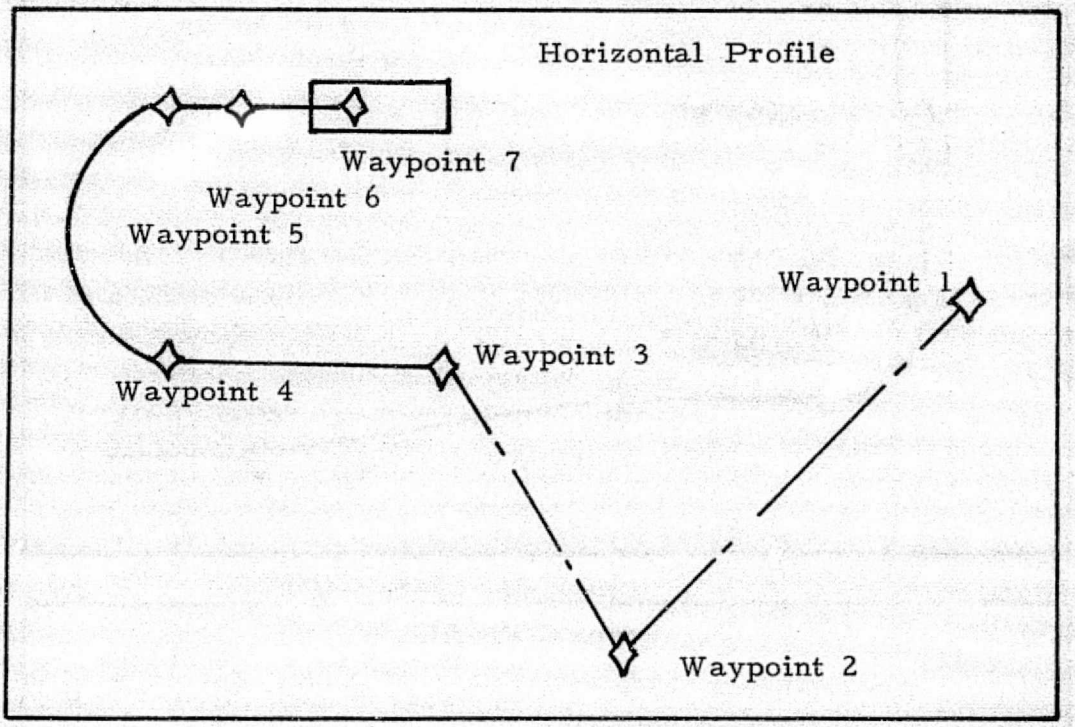


Figure A3-3

Reference Flight Path 4

Way-point	Coordinates			Flight Distance Fm Wpt 7
	x	y	z	
1	30,300	11,400	3,000	62,187
2	13,425	18,075	2,920	44,040
3	3,000	10,000	2,867	30,853
4	-6,075	10,000	2,867	21,778
5	-6,070	0	799	6,070
6	-3,798	0	500	3,798
7	0	0	0	0



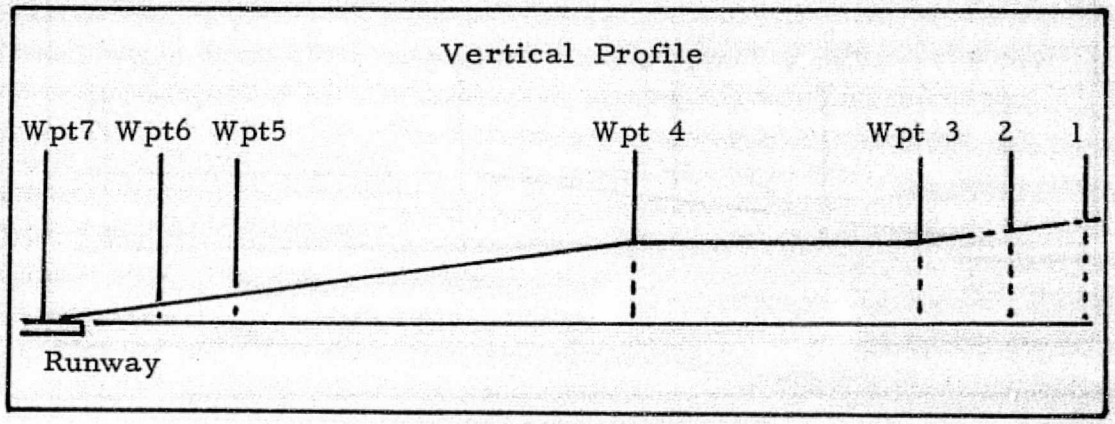
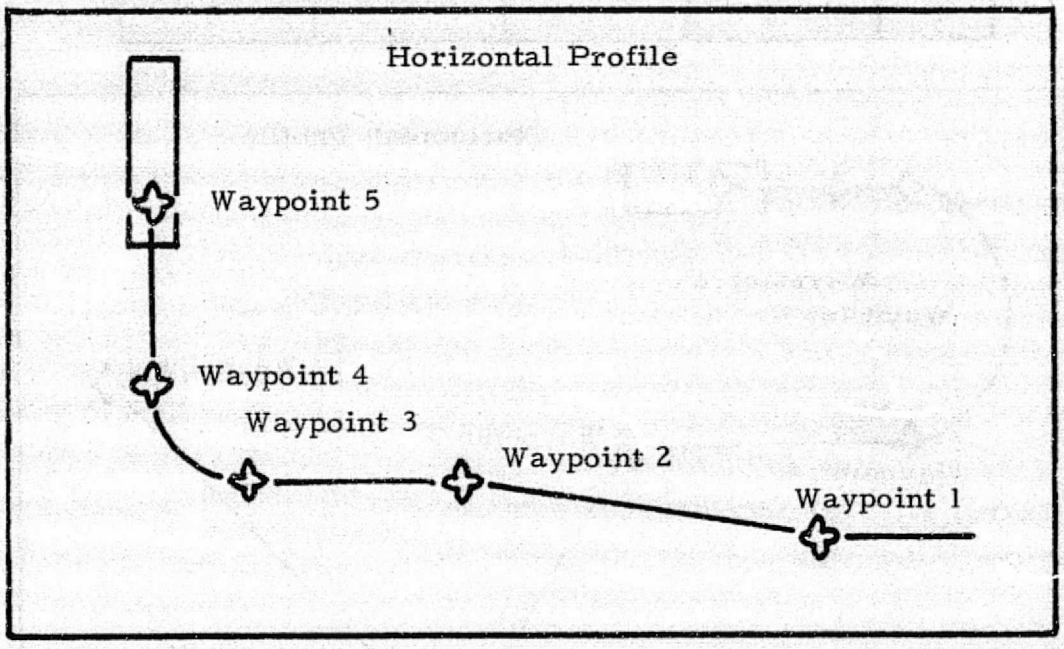


Figure A3-4

Reference Flight Path 5

Way-point	Coordinates			Flight Distance Fm Wpt 5
	x	y	z	
1	- 7,000	14,000	1,500	19,025
2	- 5,798	6,453	1,500	11,383
3	- 5,798	2,000	914	6,940
4	- 3,798	0	500	3,790
5	0	0	0	0



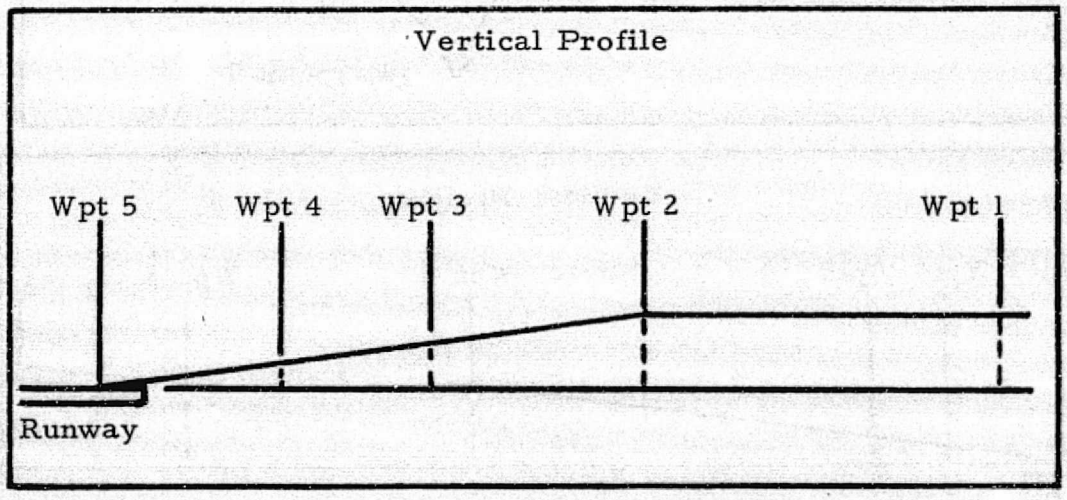
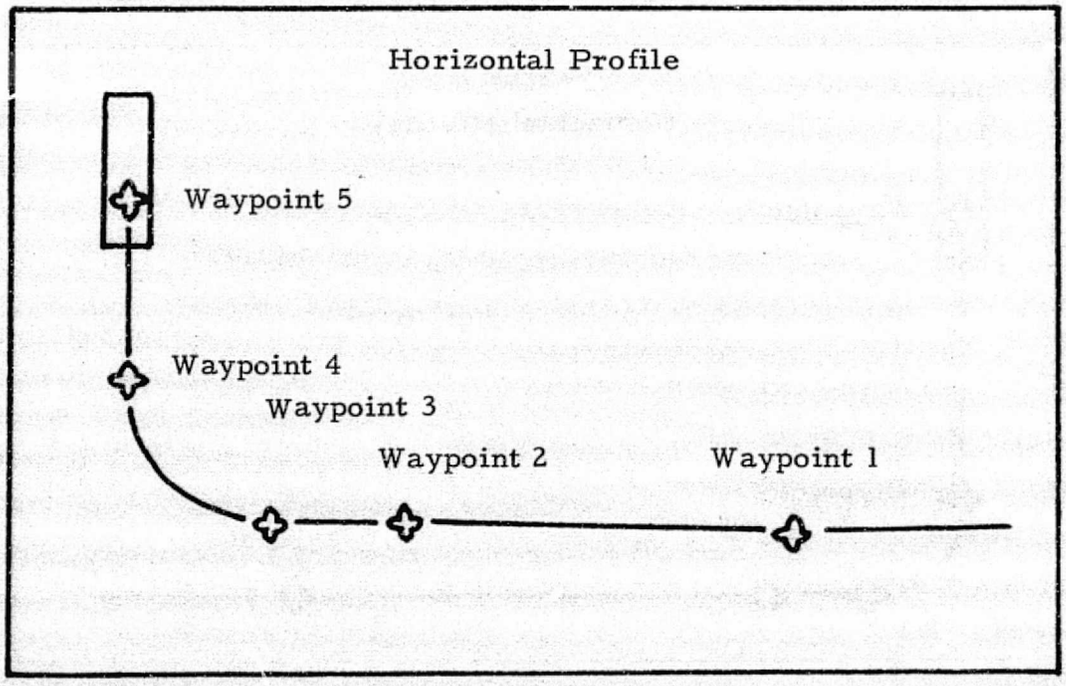


Figure A3-5

Reference Flight Path 6

Way-point	Coordinates			Flight Distance Fm Wpt 5
	x	y	z	
1	- 7,000	14,000	1,500	24,226
2	- 6,798	5,883	1,500	16,106
3	- 6,798	3,000	1,120	13,223
4	- 3,798	0	500	3,798
5	0	0	0	0



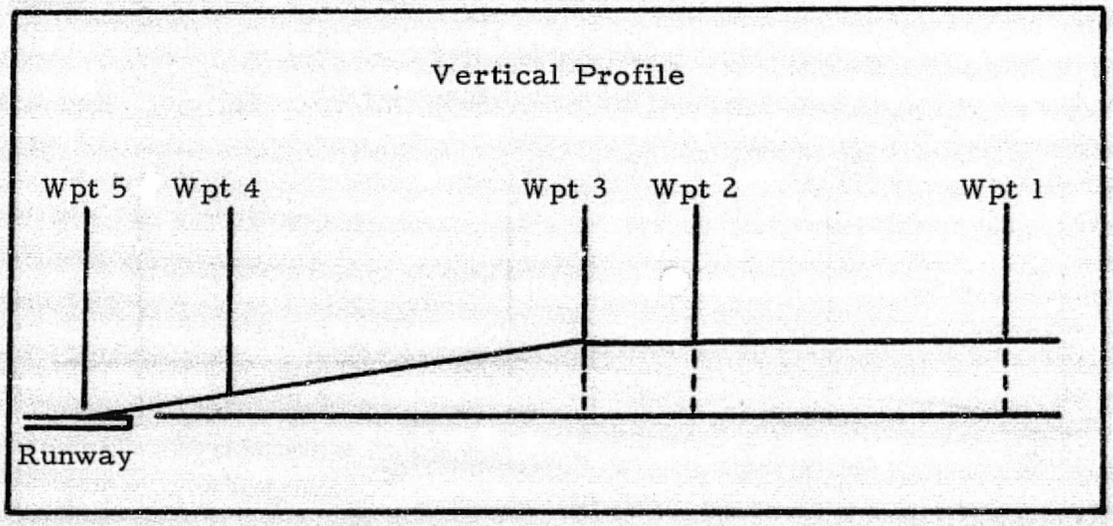
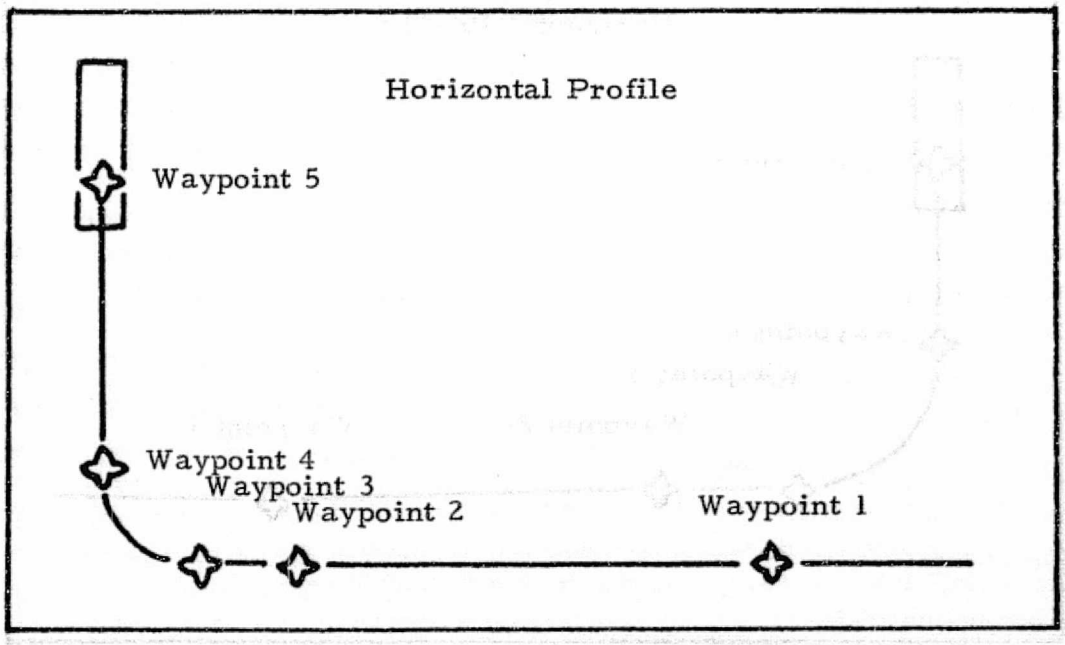


Figure A3-6

Reference Flight Path 7

Way-point	Coordinates			Flight Distance Fm Wpt 5
	x	y	z	
1	- 8,076	14,000	1,500	24,339
2	- 8,076	4,175	1,500	14,543
3	- 8,076	2,000	1,213	12,359
4	- 6,076	0	799	6,076
5	0	0	0	0



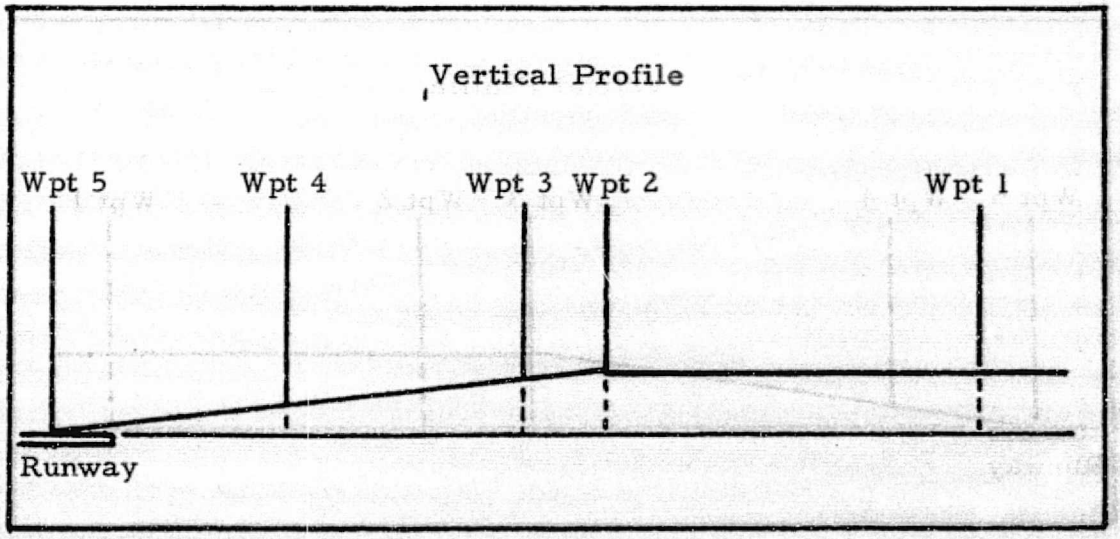
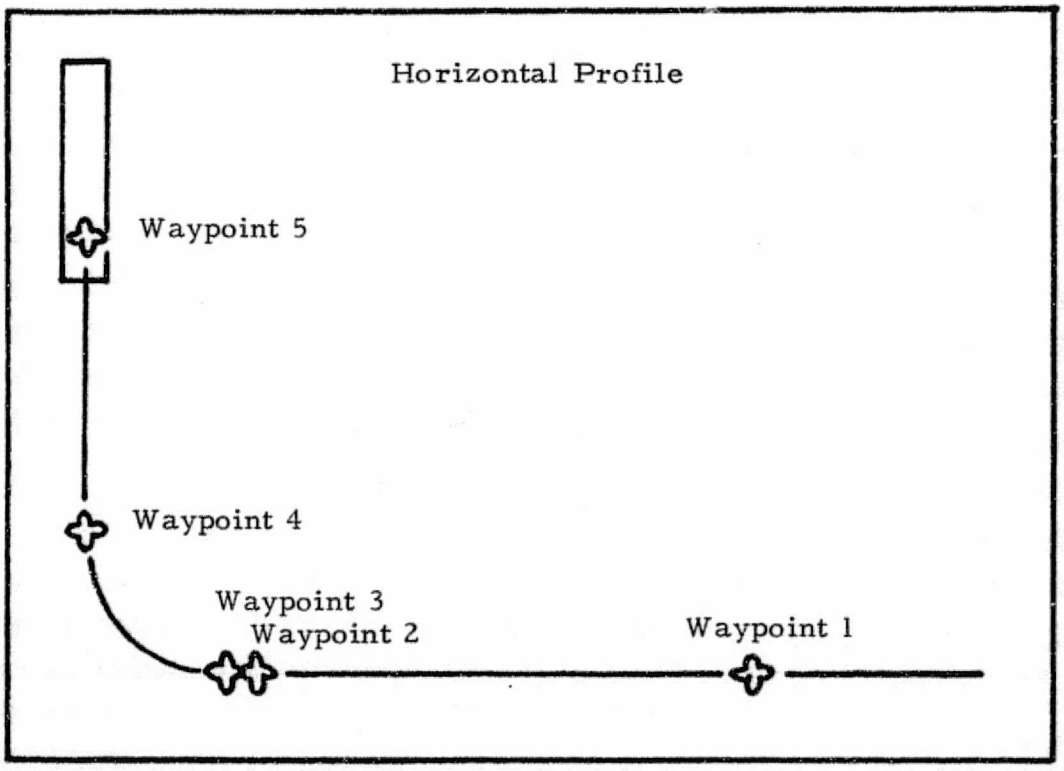


Figure A3-7

Reference Flight Path 8

Way-point	Coordinates			Flight Distance Fm Wpt 5
	x	y	z	
1	- 9,076	14,000	1,500	26,501
2	- 9,076	3,608	1,500	16,109
3	- 9,076	3,000	1,420	15,501
4	- 6,076	0	799	6,076
5	0	0	0	0



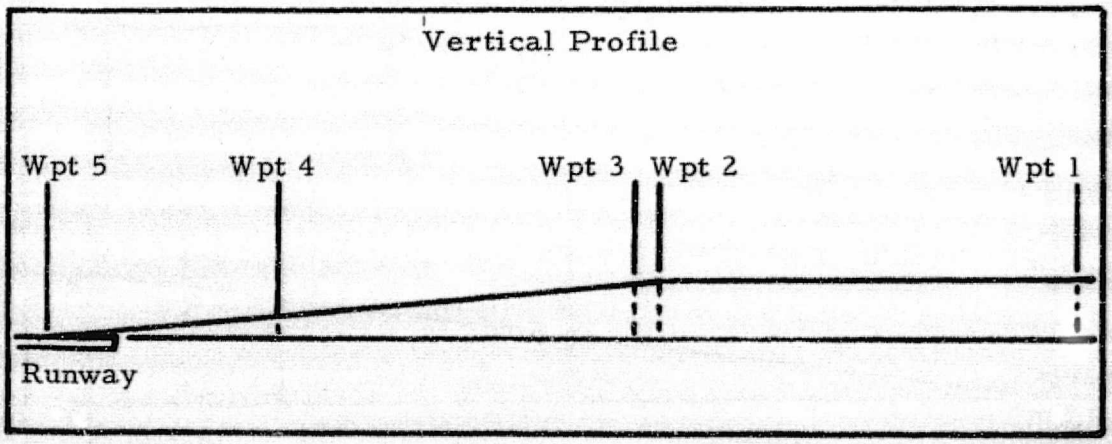
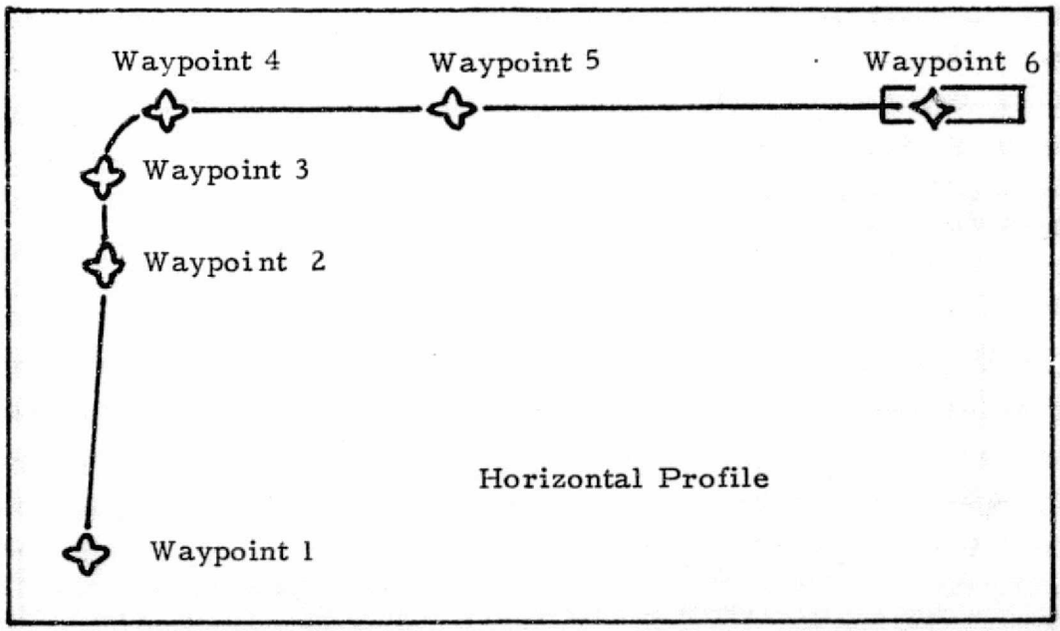


Figure A3-8

Reference Flight Path 9

Way-point	Coordinates			Flight Distance Fm Wpt 6
	x	y	z	
1	-26,800	14,000	4,000	39,460
2	-26,304	4,939	4,000	30,385
3	-26,304	2,000	3,613	27,446
4	-24,304	0	3,199	24,304
5	-15,192	0	2,000	15,192
6	0	0	0	0



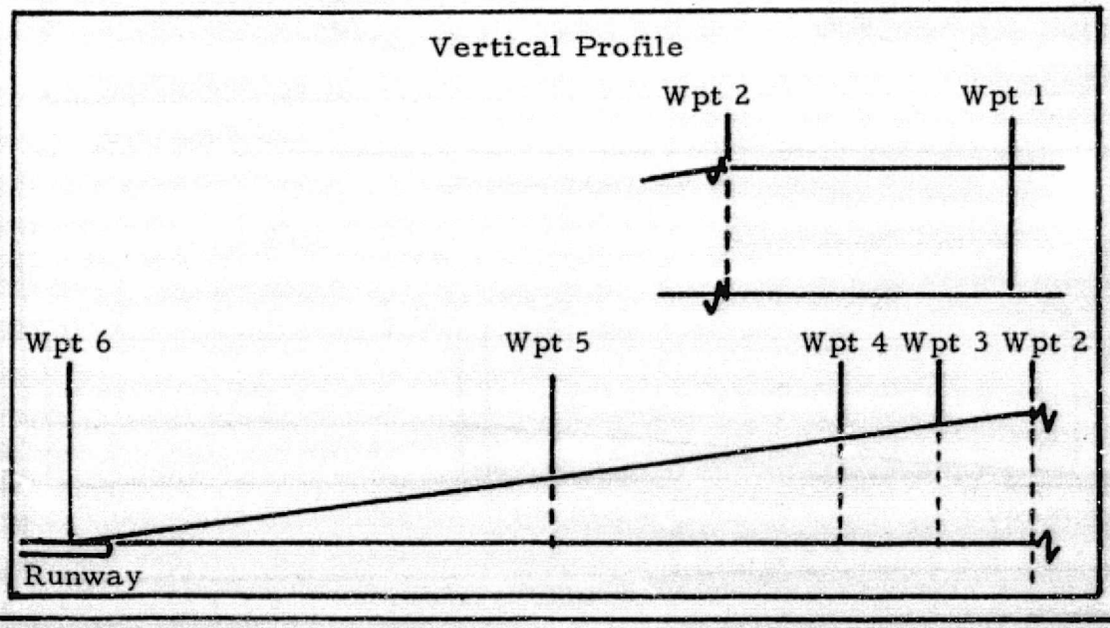
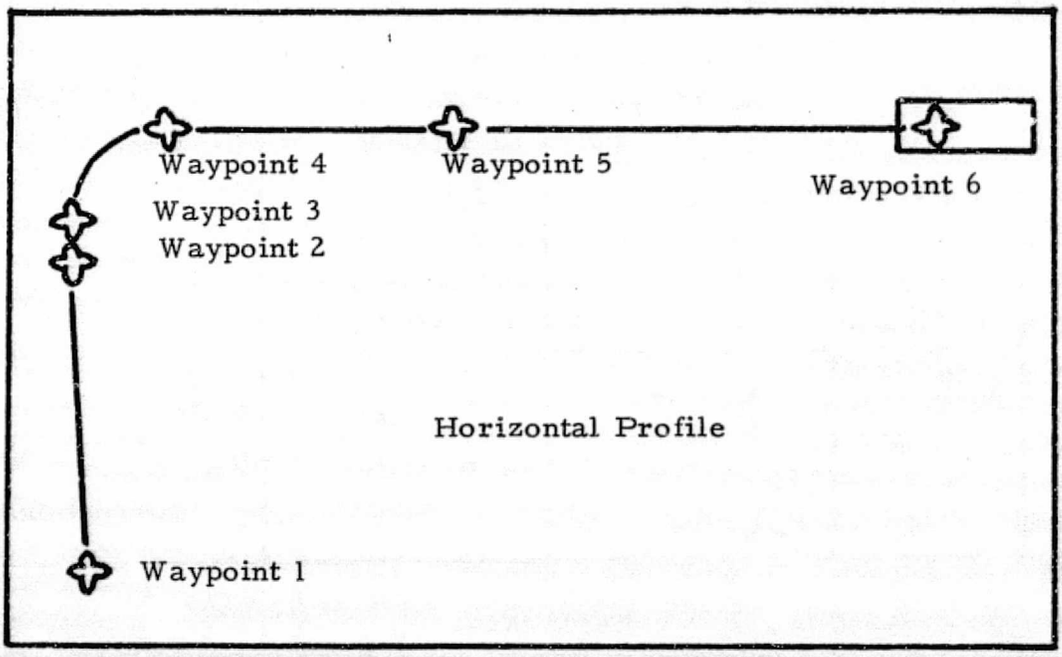


Figure A3-9

Reference Flight Path 10

Way-point	Coordinates			Flight Distance Fm Wpt 6
	x	y	z	
1	-26,800	14,000	4,000	40,029
2	-27,304	4,276	4,000	30,283
3	-27,304	3,000	3,820	29,016
4	-24,304	0	3,199	24,304
5	-15,192	0	2,000	9,112
6	0	0	0	0



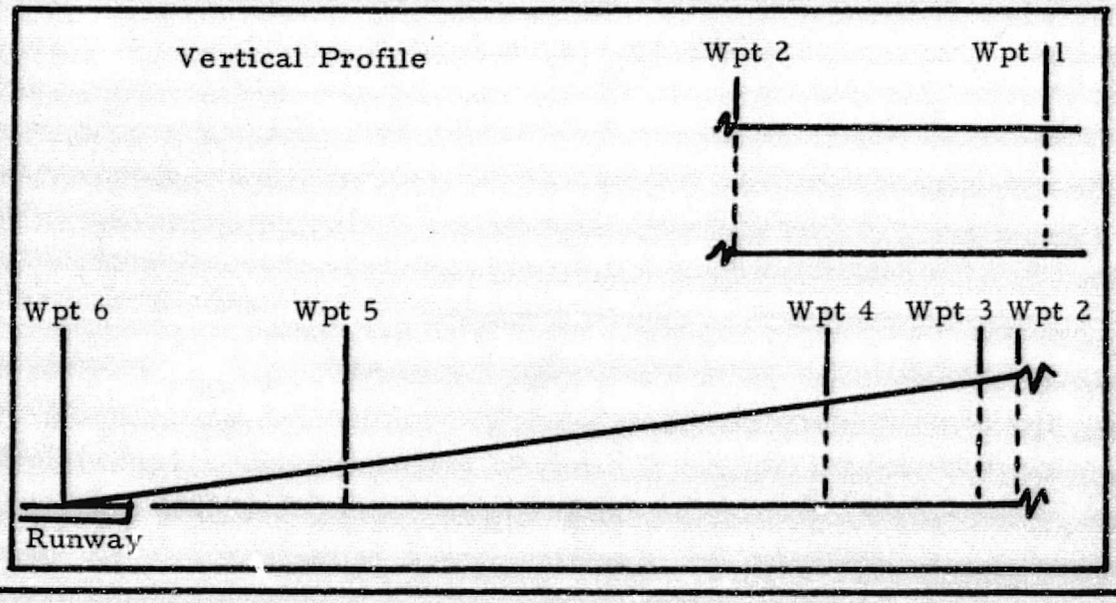


Figure A3-10

Portion of Approach		Wpt 2 - 3	Wpt 3 - 4	Wpt 4 - 6	Run
Time	0 Wind	80 sec	75 sec	57 sec	19
	323°/40 kt =4.5	48 sec	97 sec	110 sec	20
	023°/40kt =4.5	54 sec	78 sec	107 sec	21
Bank	0 Wind	7°L 12 sec Level 20 sec	11°R 9 sec 12° peak 10° steady	Level in 5 sec ±2° corrections past Wpt 5	19
	323°/40kt =4.5	15°L 10 sec Level 21 sec	26°R 10 sec 10°R for 10 sec 5°R in 10 sec 3°R 40 sec	±2° corrections past Wpt 5 ±5° corrections	20
	023°/40kt =4.5	11°L 8 sec 11°L for 5 sec 5°L 8 sec 5°L for 5 sec Level 12 sec	22°R 14 sec 22-18-22° 15 sec 11°R 5 sec 2° at Wpt 4	Level in 5 sec ±2° corrections past Wpt 5 ±4° corrections	21

Table A3-1

Wind Variations RFP 3
8/4/76

Parameter		Waypoint 1	Waypoint 2	Waypoint 3	Waypoint 4	Waypoint 5 (flare)
Bank		0	0	+6	+8	0
Pitch		+2	+3	-5	-4	-4
Angle of Attack		+2	+3	+3	+3	+4
Lateral Deviation		+off scale	-8	-16	-22	-22
Vertical Deviation		-130	+175	-25	+25	+25
Altitude		1500	1450	1100	500	8
RPM		93	94	93	96	96
Airspeed	EAS	83	80	74	69	69
	G/S	58	71	71	70	

Table A3-2

Waypoint Data Run 8/3-5
RFP 6

Parameter	Waypoint	Time	Remarks
Bank Angle	Wpt 1 to Wpt 2	82 sec	Maneuvering left bank to converge.
	Wpt 2 to Wpt 3	24 sec	Level
	Wpt 3 to Wpt 4	39 sec	Roll right to 5 1/2° in 8 seconds, shallowing to 4°, holds steady at 4°.
	Wpt 4 to Wpt 5	32 sec	Rolls level in 4 seconds, slight roll oscillation of 1° variation.
Pitch Angle	Wpt 1 to Wpt 2	82 sec	Increase to about 3 1/2° with ±1/2° oscillation of about 17 second period.
	Wpt 2 to Wpt 3	24 sec	Decreases to -6 1/2° in 20 seconds, then back up to -5°.
	Wpt 3 to Wpt 4	39 sec	Increase up to -2° in 12 seconds, then slowly decreases to -4°.
	Wpt 4 to Wpt 5	32 sec	Increased to -3° then decreased to -5°, then steadied at -4°.
Lateral Path Error	Wpt 1 to Wpt 2	82 sec	Slowly converges to +8' in 40 seconds, holds there, moves to -8' at waypoint.
	Wpt 2 to Wpt 3	24 sec	Held steady at -8' for 18 seconds. . . at this point the error increased with a 5' variation up to +16'.
	Wpt 3 to Wpt 4	39 sec	Decreases from +16' to -16' with the same variation.

Table A3-3

Flight Parameter Variations
Run 8/3-5 RFP 6

Parameter	Waypoint	Time	Remarks
Lateral Path Error	Wpt 4 to Wpt 5	32 sec	Holds steady at -22'
Vertical Path Error	Wpt 1 to Wpt 2	82 sec	Large initial oscillation then converges on 0 with several oscillations of 17 second period.
	Wpt 2 to Wpt 3	24 sec	200' $\pm$ variation at the transition, moving up to -35' at the waypoint.
	Wpt 3 to Wpt 4	39 sec	Steady increase from -35' to -25'.
	Wpt 4 to Wpt 5	32 sec	Holds steady at +25'.
Elevator Deflection	Wpt 1 to Wpt 2	82 sec	Slight decrease from $+2^{\circ}$ to -2° then up to $+4^{\circ}$ then decrease to $+2^{\circ}$ then essentially steady.
	Wpt 2 to Wpt 3	24 sec	Two minor variations.
	Wpt 3 to Wpt 4	39 sec	Held about -2° with very slight increase to waypoint.
	Wpt 4 to Wpt 5	32 sec	Initial increase to $+2^{\circ}$ then held steady at 0.
RPM	Wpt 1 to Wpt 2	82 sec	Initial large oscillation 89-97% then oscillations with 17 seconds period.
	Wpt 2 to Wpt 3	24 sec	Decrease to 89% then back to a steady 93%.
	Wpt 3 to Wpt 4	39 sec	Stays steady for 15 seconds then increases to 96%.

Table A3-3 (continued)

Flight Parameter Variations

Parameter	Waypoint	Time	Remarks
RPM	Wpt 4 to Wpt 5	32 sec	Up to 99% then decreases to 96%.
Air-Speed	Wpt 1 to Wpt 2	82 sec	Slowly decreased to 80 knots, has the 17 second period oscillation.
	Wpt 2 to Wpt 3	24 sec	Decrease to 72 knots, then back up to 74 knots.
	Wpt 3 to Wpt 4	39 sec	Decreases slowly to 67 knots.
	Wpt 4 to Wpt 5	32 sec	Holds steady with a 1 knot increase and decrease.

Table A3-3 (continued)
Flight Parameter Variations

Parameter		Waypoint 1	Waypoint 2	Waypoint 3	Waypoint 4	Waypoint 5 (flare)
Bank		-20	0	+6	+12	0
Pitch		+3	+3	-5 1/2	-3	-4
Angle of Attack		+2 1/2	+4	+6	+5	+4
Lateral Deviation		- off scale	+12	+20	+8	+4
Vertical Deviation		-90	+160	-75	+25	+25
Altitude		1500	1450	1250	800	10
RPM		96	93	93	95	95
Airspeed	EAS	85	79	75	68	70
	G/S	76	68	71	70	

Table A3-4

Waypoint Data Run 8/3-8
RFP 7

Parameter	Waypoint	Time	Remarks
Bank Angle	Wpt 1 to Wpt 2	76 sec	Maneuvering -20° to +18° then steady on level flight in 22 seconds.
	Wpt 2 to Wpt 3	19 sec	Level flight to start of turn.
	Wpt 3 to Wpt 4	26 sec	Rolls into +14°, shallows to +12°.
	Wpt 4 to Wpt 5	51 sec	Rolls level in 5 seconds and holds essentially level, slight corrections.
Pitch Angle	Wpt 1 to Wpt 2	76 sec	Some variation initially +3° to +1° to +4° to +2° to +5° then steady at about +3°.
	Wpt 2 to Wpt 3	19 sec	Decreases to -5 1/2° during the transition.
	Wpt 3 to Wpt 4	26 sec	During the turn, the pitch eased up to -1 1/2° then down to -3°.
	Wpt 4 to Wpt 5	51 sec	Eases down to -5° then steadies at -4°.
Lateral Path Error	Wpt 1 to Wpt 2	76 Sec	Slowly converging to +12'.
	Wpt 2 to Wpt 3	19 sec	Increases to +30' then back to +20' with a small data oscillation.
	Wpt 3 to Wpt 4	26 sec	Decreased down to +8'.
	Wpt 4 to Wpt 5	51 sec	Drops to -4' and stays steady
Vertical Path Error	Wpt 1 to Wpt 2	76 sec	Large correction -90' to +50' converges to 0 with several 17 second period oscillations.

Table A3-5

Flight Parameter Variations
Run 8/3-8 RFP 7

Parameter	Waypoint	Time	Remarks
Vertical Path Error	Wpt 2 to Wpt 3	19 sec	+160' -150' variation during transition up to -75' at waypoint.
	Wpt 3 to Wpt 4	26 sec	Converges to +25'.
	Wpt 4 to Wpt 5	51 sec	Holds steady at +25'.
Elevator Deflection	Wpt 1 to Wpt 2	76 sec	Maneuvering deflection for 20 seconds then steady at $+2^{o}$.
	Wpt 2 to Wpt 3	19 sec	$+2^{o}$ to -2° to $+4^{o}$ during transition.
	Wpt 3 to Wpt 4	26 sec	Eases from -1° to -3° during turn.
	Wpt 4 to Wpt 5	51 sec	Increases to $+3^{o}$ at completion of turn then holds steady at 0.
RPM	Wpt 1 to Wpt 2	76 sec	Large oscillations at start then holds 91-94% with 17 second period oscillation.
	Wpt 2 to Wpt 3	19 sec	Decrease from 93 to 89% then back to 93%.
	Wpt 3 to Wpt 4	26 sec	Holds 93% half way through turn then increases to 95% at waypoint.
	Wpt 4 to Wpt 5	51 sec	Increased to 99% as airplane rolls level then decreases to 95%.

Table A3-5 (continued)
Flight Parameter Variations

Parameter	Waypoint	Time	Remarks
Air-Speed	Wpt 1 to Wpt 2	76 sec	Starts at 85knots, decreasing to 79 knots with a 17 second period oscillation.
	Wpt 2 to Wpt 3	19 sec	Slowly decreases to 75 knots.
	Wpt 3 to Wpt 4	26 sec	Slowly decreases to 68 knots.
	Wpt 4 to Wpt 5	51 sec	Increased to 70 knots and holds steady.

Table A3-5 (continued)

Flight Parameter Variations

Parameter		Waypoint 1	Waypoint 2	Waypoint 3	Waypoint 4	Waypoint 5 (flare)
Bank		+26	0	+4	+8	0
Pitch		+10	+3	+2 1/2	-3	-4
Angle of Attack		+4	+4	+7	+5	+3 1/2
Lateral Deviation		+ off scale	+16	+8	-20	-30
Vertical Deviation		-125	+175	-60	+20	+20
Altitude		1450	1500	1400	800	10
RPM		98	91	91	99	96
Airspeed	EAS	85	79	76	69	70
	G/S	51	72	73	70	

Table A3-6

Waypoint Data Run 8/3-10
RFP 8

Parameter	Waypoint	Time	Remarks
Bank Angle	Wpt 1 to Wpt 2	119 sec	Maneuvering with bank to -28° for 30 seconds.
	Wpt 2 to Wpt 3	5 sec	Steady at level flight to waypoint 3.
	Wpt 3 to Wpt 4	38 sec	Smooth roll into $+10^{o}$, slight increase to $+11^{o}$, then shallows to 9° at waypoint 4.
	Wpt 4 to Wpt 5	51 sec	Rolls level within 5 seconds and holds nearly steady.
Pitch Angle	Wpt 1 to Wpt 2	119 sec	Large pitch changes during initial capture, settling to about $+3^{o}$ at waypoint 2.
	Wpt 2 to Wpt 3	5 sec	Drifts to $2\ 1/2^{o}$ as the descent is started.
	Wpt 3 to Wpt 4	38 sec	Decreases to 0° in about 5 seconds and continues down to -5° then increases to -3°.
	Wpt 4 to Wpt 5	51 sec	Decreased to -5° then steadies to -4° to flare.
Lateral Path Error	Wpt 1 to Wpt 2	119 Sec	Comes from off scale to 2 overshoots prior to convergence.
	Wpt 2 to Wpt 3	5 sec	Decreases from +16' down to +8'.
	Wpt 3 to Wpt 4	38 sec	Continues to decrease to -20'
	Wpt 4 to Wpt 5	51 sec	Drops abruptly to 30' and holds steady.

Table A3-7

Flight Parameter Variations
Run 8/3-10 RFP 8

Parameter	Waypoint	Time	Remarks
Vertical Path Error	Wpt 1 to Wpt 2	119 sec	Large corrections and positive overshoot then slow convergence to 0 at waypoint 2 with 17 second period oscillations.
	Wpt 2 to Wpt 3	5 sec	+175'- 60' variation during transition.
	Wpt 3 to Wpt 4	38 sec	Continues down to -180' as the transition goes past waypoint 3. After transition, slowly comes up to +20'.
	Wpt 4 to Wpt 5	51 sec	Holds steady at +20'
Elevator Deflection	Wpt 1 to Wpt 2	119 sec	Maneuvering for about 20 seconds, then holds nearly steady at $+2^{o}$ to $+3^{o}$.
	Wpt 2 to Wpt 3	5 sec	Slowly decreasing during transition.
	Wpt 3 to Wpt 4	38 sec	Some maneuvering for 15 seconds, then holds steady at -2° until just prior to the completion of the turn.
	Wpt 4 to Wpt 5	51 sec	Initial maneuvering for 5 seconds, then steady at 0.
RPM	Wpt 1 to Wpt 2	119 sec	Decreasing from 98% to 89% then goes to a 93-94% oscillation with a 17 second period.
	Wpt 2 to Wpt 3	5 sec	Decreasing from 91% to 89% momentarily as descent starts then back up to 91%.

Table A3-7 (continued)

Flight Parameter Variations

Parameter	Waypoint	Time	Remarks
RPM	Wpt 3 to Wpt 4	38 sec	Continues to increase to 93% holds steady there until just prior to completion of turn then increases to 94% at waypoint 4, then goes right up to 99%.
	Wpt 4 to Wpt 5	51 sec	Slowly decreases to 96%.
Airspeed	Wpt 1 to Wpt 2	119 sec	Decreased from 85 to 72 knots, then back up to 80 knots - the 17 second period oscillation is detectable here.
	Wpt 2 to Wpt 3	5 sec	Decrease to 76 knots.
	Wpt 3 to Wpt 4	38 sec	Increases to 97 then slows to about 70 knots.
	Wpt 4 to Wpt 5	51 sec	Holds nearly steady at 70 knots.

Table A3-7 (continued)

Flight Parameter Variations

NASA CR -137975

November 1976

APPENDIX 4

Wind effect raw data
extracted during simulation
including comments and analysis

Appendix 4

The pilot is very concerned with the change in his approach caused by wind and wind shear. The shear effect was not examined because of simulation limitations. Wind will usually increase the pilots workload and can produce large bank angle requirements for turns. It can also alter the times required for each portion of an approach. Data run 11 through 16 of 8/3/76 had a wind of $323^{o}/40$ knots with turbulence. This wind produces a 35 knot headwind component, and a 20 knot cross wind component on final approach with the reverse on base leg.

Table 8 compares time in the various segments of the approach against bank angles of data runs 8/3-3 and 8/3-12 (with and without wind). These approaches have a 2,000 foot turn radius.

Portion of Approach		Wpt 2 to Wpt 3	Wpt 3 to Wpt 4	Wpt 4 to Wpt 5	Run
Time	No Wind	37 sec	27 sec	38 sec	Run 3
	Wind	47 sec	39 sec	56 sec	Run 12
Bank	No Wind	0°	12°	0°	Run 3
	Wind	$\pm 2^{o}$	4°	$\pm 3^{o}$	Run 12

Table A4-1

Generally the wind and turbulance causes the vertical error, pitch angle and RPM oscillations to increase in magnitude and shorten the period of oscillation to about 14 seconds. The headwind component did increase the time between each waypoint. It also reduced the ground speed so that the bank angle was reduced during the turn. This is an improvement in the

approach. The turbulance also caused some bank corrections during the straight portions of the approach. The descent, final turn, and final approach are still satisfactory, even though the vertical oscillations continue through the final turn to Waypoint 4.

Table 9 compares time in the various segments of the approach and bank angles of data runs 8/3-5 and 8/3-13 (with and without winds). These approaches have a 3,000 foot turn radius.

Portion of Approach		Wpt 2 to Wpt 3	Wpt 3 to Wpt 4	Wpt 4 to Wpt 5	Run
Time	No Wind	24 sec	39 sec	32 sec	Run 5
	Wind	38 sec	82 sec	72 sec	Run 13
Bank	No Wind	0°	5°	0°	Run 5
	Wind	$\pm 2^{o}$	$2\ 1/2^{o}$	$\pm 3^{o}$	Run 13

Table A4-2

On these runs the wind caused the bank angle of Run 8/3-13 to shallow out to $2\ 1/2^{o}$ and extended the final turn time. Other than that, its effect is no different than wind effect on a standard ILS. On Run 8/3-15, which had a 2,000 foot turn radius, the airspeed was at 80 knots instead of 70, and the bank angle between Waypoints 3 and 4 was 5° as compared to Run 8/3-3's 12°. It appears that increasing the airspeed for a high headwind improves the approach in much the same manner as is done in CTOL airline operations today.

Examination of the printed data below 500' ATZ for Run 8, with calm winds and Run 8/3-15 with a wind of 323°/40 knots and a turbulance level of 4.5 (both runs that have a one mile final approach, as shown in tables A4-3

and A4-4 shows an interesting comparison.

Vertical Path	500'	400'	300'	200'	100'	
Bank Angle	0.36	-0.69	0.26	0.53	-0.30	Degrees
Pitch Angle	-4.43	-3.97	-3.91	-4.13	-4.02	Degrees
Vertical CG Position	7.82	8.97	9.46	7.90	8.83	Feet
Lateral CG Position	-16.93	-9.25	-3.58	1.14	6.58	Feet
Airspeed	70	70	70	70	70	Knots

Specific Flight Parameters vs Altitude
Data Run 8/3-8 RFP 8
Table A4-3

Vertical Path	500'	400'	300'	200'	100'	
Bank Angle	-0.98	0.64	0.15	0.27	1.04	Degrees
Pitch Angle	-6.51	-5.01	-4.46	-3.92	-5.02	Degrees
Vertical CG Position	9.27	8.34	9.28	9.60	8.19	Feet
Lateral CG Position	6.07	7.05	13.64	16.13	10.62	Feet
Airspeed	78	85	85	86	78	Knots

Specific Flight Parameters vs Altitude
Data Run 8/3-15 RFP 8
Table A4-4

The bank angle during Run 15 was not increased appreciably in magnitude, but there was a greater frequency of variation. The magnitude of pitch angle change is apparent. This would be expected because of the necessity to overcome vertical gusts produced by the turbulence. The vertical position of the center of gravity for Run 15 is nearly the same as that of Run 8. The Lateral Position shows some differences. In Run 8, the CG is off to the left by about 17 feet at the 500' point and it angles back to centerline by 200',

then moves to about 6' right at the 100' point. Run 15 has the crosswind from the left and the CG is 6' right of centerline at the 500' point and increases to 16' at the 200' point then comes back to 10' right at the 100' point. The airspeed is much steadier in Run 8 as could be expected in calm winds, but the added airspeed still shows only a 7 knot variation with a wind condition that has a 30 knot headwind component with turbulance.

Table A4-5 compares the crosswind effects on the 2,000 foot turn radius of RFP 7 and the 3,000 foot turn radius of RFP 8. The only significant difference in this comparison is the average bank angle used in the final turn. The 2,000 foot turn radius shows 2 more degrees magnitude than does the larger turn radius.

		Time & Average Airspeed			Avg Bank in Final Turn	Total Error At completion of turn	
		Wpt 2-3	3-4	4-5			
		sec-kts	sec-kts	sec-kts		Lateral	Vertical
Reference Flight Path 7	Run 3 023° 40 kts	19 - 70	27 - 70	56 - 70	6 1/2°	-7 ft	+17 ft
	Run 6 320° 40 kts	18 - 76	27 - 69	56 - 70	6 1/2°	-8 ft	+25 ft
	Run 8 8/3/76 Wind 0/0	19 - 77	26 - 70	51 - 70	6 1/2°	+8 ft	+25 ft
Reference Flight Path 8	Run 5 023° 40 kts	5 - 79	40 - 70	56 - 70	4 1/2°	+5 ft	+30 ft
	Run 7 323° 40 kts	5 - 79	40 - 70	57 - 70	4 1/2°	+4 ft	+25 ft
	Run 10 8/3/76 Wind 0/0	5 -77	38 - 71	51 - 70	4 1/2°	-20 ft	+20 ft

Table A4-5

Crosswind Comparisons of RFP 7 and RFP 8

Wind effects on the 180° turn approach were examined on Runs 19, 20, and 21, flown 8/4/76. These Runs use reference flight path 3. Run 19 had calm winds, Run 20 had a wind of 323°/40 knots which provided a right quartering tail wind from waypoints 2 to 3; a cross wind from waypoint 3 to 4, with right drift and a deadwind component; and a left quartering wind on final. Run 21 had a wind of 023°/40 knots, which provided a left quartering tailwind from waypoint 2 to 3; a crosswind from waypoints 3 to 4 with left drift and a tailwind component; and a right quartering headwind on final. Table A4-6 summarizes the time and bank angle of this flight path with the various winds.

Portion of Approach		Wpt 2 - 3	Wpt 3 - 4	Wpt 4 - 6	Run
Time	0 Wind	80 sec	75 sec	57 sec	19
	323°/40 kt ≈4.5	48 sec	97 sec	110 sec	20
	023°/40kt ≈4.5	54 sec	78 sec	107 sec	21
Bank	0 Wind	7°L 12 sec Level 20 sec	11°R 9 sec 12° peak 10° steady	Level in 5 sec ±2° corrections past Wpt 5	19
	323°/40kt ≈4.5	15°L 10 sec Level 21 sec	26°R 10 sec 10°R for 10 sec 5°R in 10 sec 3°R 40 sec	±2° corrections past Wpt 5 ±5° corrections	20
	023°/40kt ≈4.5	11°L 6 sec 11°L for 5 sec 5°L 8 sec 5°L for 5 sec Level 12 sec	22°R 14 sec 22-18-22° 15 sec 11°R 5 sec 2° at Wpt 4	Level in 5 sec ±2° corrections past Wpt 5 ±4° corrections	21

Table A4-6
Wind Variations RFP 3
8/4/76

The quartering tailwind (Run 20) shortens the time on downwind leg (waypoint 2 to waypoint 3). The crosswind during the 180° final turn lengthens the turning time during the last 90°. The time on the final approach is naturally lengthened by the headwind component.

The bank angles required by the 3,000 foot turn radius during calm winds are small enough to be satisfactory during low visibility and low ceiling approaches. The 12° bank angle reached while following the flight path during the turn is satisfactory for the 75 second period of the final turn. When the winds are applied, the crosswind (323°/40 kts of Run 20) required a 26° bank to start the turn to final. This requirement lasted for only a relatively short period of time (10 seconds) and at this point in the approach did not present an operational problem. The bank reduced to 10°, and then for the last 50 seconds of the turn, the bank angle is 5° or less. This produces good turning qualities and would reduce pilot work load. The other crosswind (023°/40 kts of Run 21) uses less bank initially (22°) but has more variation in bank as the airplane follows the curved path. The wind helps the airplane around the turn and only 11° of bank is required past the half way point. This is simular to the calm wind condition during the last part of the turn. The bank shallows to about 2° as the headwind component increases.

The wind effect on final approach is about the same with either crosswind.