THE CANADIAN STOL DEMONSTRATION - THE DATA COLLECTION THE FINDINGS AND THEIR APPLICATIONS

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ABSTRACT

The Canadian Government sponsored a STOL Demonstration Service to commercial air carrier standards between the cities of Montreal and Ottawa between August 1974 and March 1976. The objectives of this program were to test the technical feasibility and public acceptance of STOL systems.

The Canadian Air Transportation Administration (CATA) STOL Project Team conducted a data collection and monitoring exercise capable of providing the information required to establish the technical standards and operational procedures for STOL transportation. This paper describes the demonstration operating concepts and the data collection exercises and summarizes the results showing how they will be used to make recommendations for the regulation and control of future Canadian STOL systems.

INTRODUCTION

The STOL demonstration service was completed on March 31st of this year after having completed twenty-four thousand successful flights between Ottawa and Montreal. The characteristics of this experimental service were designed to provide the data and experience base upon which a permanent STOL operation could be constructed. The purpose of this paper is to describe the experiment and the data collection exercises and to present a summary of the results and a summary of how these results are being applied to develop technical, operational, and regulatory components of a STOL air transport system. One of a number of objectives of the STOL demonstration would therefore be satisfied. Other objectives relating to economic, passenger demands, and marketing studies were conducted by other agencies of the Canadian Government.

The information in this paper is presented in three parts;

- the operating concepts, and the data collection methodology,
- a summary of the findings, and
- the application of the findings to recommendations for future STOL systems.

PART I
THE OPERATING CONCEPTS AND DATA COLLECTION METHODOLOGY

STOLport Locations

The choice of an Ottawa-Montreal routing ensured a realistic test of STOL concepts. The area provided competition from other modes of transport and it represented a high air traffic density environment. The concept of a decreased city-center to city-center travel time potential could be evaluated and the impact related to the passenger demands.

In Montreal, a parking lot left derelict from the 1967 World's Exposition was converted into a STOLport. In Ottawa, an old military airfield at Rockcliffe provided the STOLport location. These two sites were five and fifteen minutes respectively from the center of the cities.

The Operation

Airtransit, a wholly owned subsidiary of Air Canada, was incorporated to operate the two year service. Six De Havilland Twin Otters (DHC-6-300) were purchased and modified to be representative of the technology available for modern inter-city STOL systems.

Flight frequencies varied from every half-hour to every hour depending on the peak travel periods. A minibus service was provided as part of the package fare from downtown to downtown. The primary principles in the passenger processing procedures were simplicity, convenience and speed.

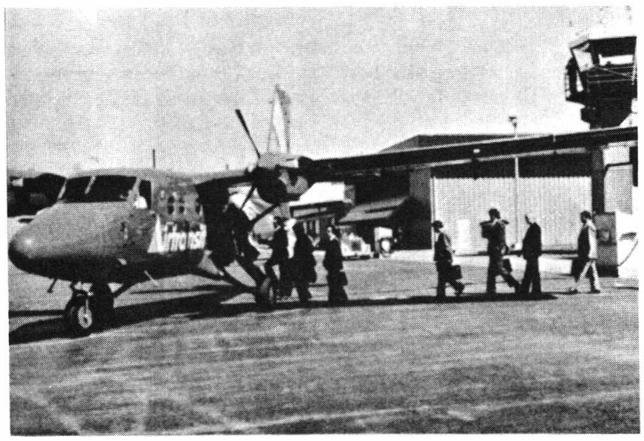


Figure 1.1

The flying times varied from forty to fifty minutes with the complete city-center to city-center time being approximately one hour and twenty minutes.

The interior of the Twin Otters were modified with an arrangement of twelve seats designed to match normal air carrier comfort standards.

STOLport Characteristics

Each STOLport featured a small passenger terminal, a car parking area, an ATC tower, a maintenance and storage building, a runway, taxiways, an apron and a complement of navigation aids and lighting systems.

Figure 1.2

The passenger terminal, parking area, and apron were structured to produce a minimal walking distance between the ground and air transportation vehicles.

The STOL runways were constructed with a length of 2,000 feet, a width of 100 feet, and an over run area of 400 feet on each end. The taxiways were built with a width of 30 feet.

An IFR precision approach capability was provided by a microwave landing system (MLS); transmitters were installed at each end of the runway at each of the STOLports. DME's were installed at both sites and hence provided a distance to go indication in lieu of an outer marker.

The STOLport lighting system consisted of taxiway and runway edge lights, touchdown zone floodlighting, VASIS, runway end identification lights, and the necessary obstruction lights.

A small hangar and airfield maintenance and emergency services building was constructed at each of the STOLports to accommodate maintenance at the sites.

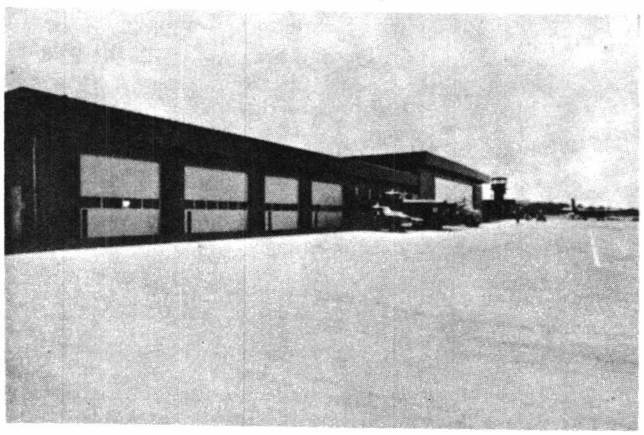


Figure 1.3

Fixed ground power outlets and fueling pumps were located at the edge of the apron to facilitate quick turn-arounds.

Route and Approach Systems

It was recognized that an intercity STOL transportation system is inherently faced with the probability of a high density, restricted airspace. An increase in the complexity is therefore guaranteed by the addition of another airport or STOLport. The route and approach systems were designed to test the navigational and operational concepts capable of minimizing the impact of another runway and the increased local traffic.

Guidance between the STOLports was provided through use of area navigation (R-NAV). Three dimensional R-NAV profiles were designed such that a fixed, dedicated path from takeoff to touchdown was pre-programmed. R-NAV route charts were produced containing all of the information required for both the enroute and approach phases of the flight. The Air Traffic Control clearance was therefore simplified to an extent that only the route number was required. Similarily, the R-NAV route provided the "airspace to be protected", eliminated the need for radar vectors, and substantially reduced the communication requirements.

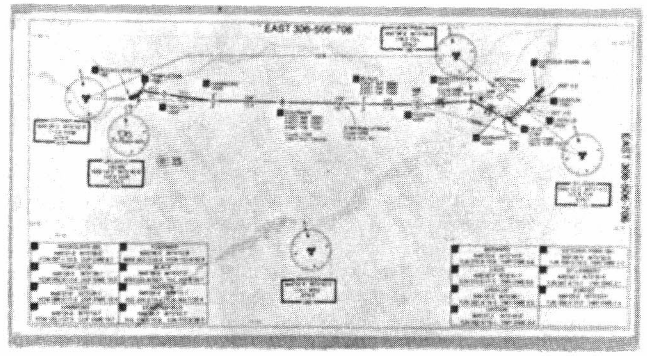


Figure 1.4

The primary approach aid was a Co-Scan MLS. Area navigation provided an approach system redundancy, and an overshoot guidance. The MLS glidepath angle was fixed within the aircraft at 6°; the R-NAV non-precision approach was designed to coincide with the MLS localizer and glidepath. The precision limits on the MLS were set at 300 feet AGL and 1/2 nm visibility. The higher non-precision R-NAV limits were set according to the signal reception capability and navigation geometry on the individual approach.

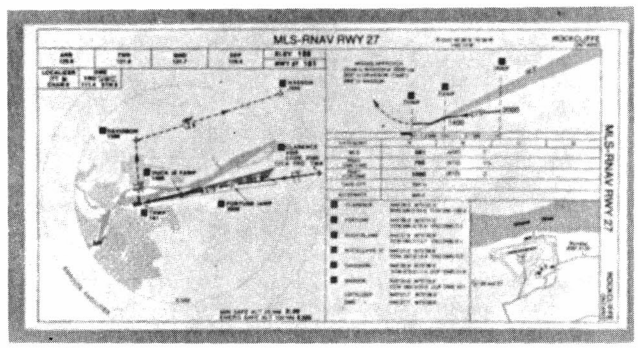


Figure 1.5

Aircraft Avionics

The aircraft were each outfitted with:

- an area navigation system,
- dual MLS receivers,
- a radio altimeter,
- dual VOR's and DME's,
- dual flight directors,
- an ADF,
- a marker receiver,
- a navigation status panel,
- an auto pilot,
- a weather radar,
- an ATC transponder, and
- dual VHF communication system

as well as normal IFR instrumentation requirements.

The area navigation equipment consisted of a Litton 101 (modified) system capable of storing up to 30 waypoints. All of the useable reference stations were hardwired into the Navigation Computer Unit (NCU) and were automatically called up and tuned as required. The mode of navigation was primarily DME/DME, with VOR/DME providing a redundancy. Route and approach information were entered into the system via an Automatic Data Entry Unit (ADEU) which operated by electro-optically scanning a preprinted mark sense card. Each one of these cards contained the data required to fly a profile from take-off to touchdown. Manual changes could be made via a conventional Control Display Unit (CDU). The desired path was determined for the horizontal and vertical planes. The appropriate deviation signals were fed to the flight director systems and a conventional course deviation indicator.

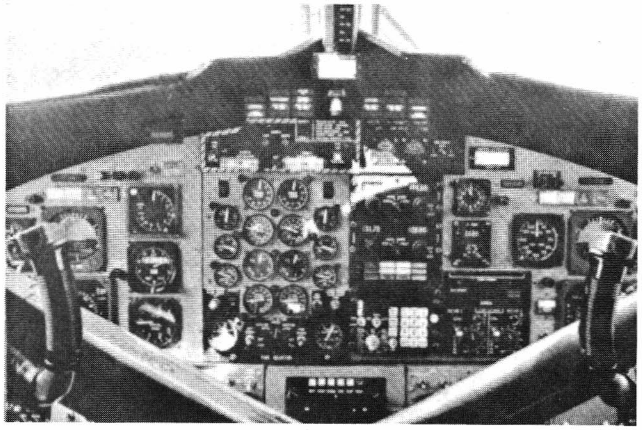


Figure 1.6

Both pilots were provided with modified Collins FD-108 Flight Director Systems. The appropriate guidance mode (R-NAV, MLS or VOR) could be selected by push-buttons directly above the flight director. The flight director sensitivities were adjusted to coincide with the slow speed aerodynamic characteristics of the aircraft, and in the approach phase reflected a continuous function of the DME distance to threshold.

The navigation status panel displayed the applicable navigation mode and presented warnings for loss of signal reception.

Aircraft Modifications

The De Havilland Twin Otter series 300 was chosen as the aircraft to be used because of its proven reliability, its STOL capability and its procurability. Safety was of paramount importance in the concept of the Demonstration and consequently the airworthiness standard of the aircraft was to be the same standard as a conventional large passenger carrying aircraft. The Twin Otter had been certified to the normal category requirements that are applicable to small aircraft operating in the general aviation field, consequently some forty to fifty modifications were incorporated to equip the basic aircraft for its role in a standard class 1 air carrier operation. Some of the more important modifications were:

- automatic propeller feathering,
- increased wheel brake capacity plus an anti-skid system,
- propeller discing and propeller reversing for glidepath control and reduced landing ground roll,
- birdproof windshield,
- airframe, propeller and engine de-icing equipment,
- hydraulic flow limiters in the wheel brake lines to reduce the possibility of hydraulic failure due to component failures,
- electrical power distribution system redesign to more nearly meet FAR 25 requirements,
- ground spoilers to reduce landing ground roll distances and provide improved ground handling characteristics under strong cross-wind and gust conditions, and
- fire detection and extinguishing systems for the power plant and baggage compartments.

Flying Crews

Forty-eight pilots were hired and comprehensively trained on the approach and route systems. The total flying experience of the aircraft Captains averaged 6,000 hours and the First Officers 2,000 hours. The pilots averaged 900 hours of flying during the demonstration service.

CATA STOL Project Team

Many private companies and government agencies worked together to design, fabricate, operate and monitor the Demonstration. The CATA STOL Project Team was given the task of developing the design of the system and components, developing specifications and coordinating the efforts of many Divisions and Branches within the Ministry who contributed to the Demonstration. Once the Service was safely underway the team coordinated the maintenance of the operational and navigation systems and assumed a data collection system monitoring role.

It is important to note that the data base was collected under actual operating conditions and therefore may be useful in substantiating or modifying the conclusions reached through closely controlled, laboratory type of experiments. The data collection was oriented towards the following studies:

- R-NAV capability in a STOL environment,
- vertical navigation (VNAV) capability enroute and in the approach,
- flight technical error (position keeping accuracy) both enroute and in the approach phase, and in the horizontal and vertical plane,
- R-NAV accuracy on the approach,
- wind shear and turbulence in the approach areas,
- height dispersion over the threshold,
- normal and lateral aircraft accelerations,
- aircraft touchdown dispersion,
- adequacy of the STOLport lighting systems,
- air traffic control considerations,
- suitability of STOLport characteristics,
- landing ground roll, and
- airspeed dispersion on the approach.

Data Collection Exercises

Data collection during the demonstration was conducted by different agencies according to their area of interest. The CATA STOL Project Team conducted data collection exercises oriented towards the technical and operational elements observed in the previous paragraph.

Air Data Acquisition System. The primary source of technical and operational data was the Air Data Acquisition System (ADAS) which was installed in the Airtransit aircraft. Each system included a recorder electronics unit, two recorders, an elapsed time dispay along with the many parameter sensors and the connecting wiring.

Approximately 30 variables and 22 discrete functions were recorded continuously in standard 9 track parallel format on magnetic tape. A list of the information recorded is shown in Table 1.1.

TABLE 1.1

INFORMATION RECORDED BY ADAS

PARAMETERS	DISCRETES
Glide Slope Deviation	**Navigation Mode**
Localizer Deviation	MLS
Cross Track Deviation	R-NAV
Vertical Deviation	VOR/LOC
Roll Command	
Pitch Command	**Area Navigation Mode**
Roll Angle	DME/DME
Pitch Angle	VOR/DME
Magnetic Heading	Memory
Airspeed Error	
Barometric Altitude	**Functions**
Radio Altimeter Height	Auto Tune
DME No. 1	Waypoint Alert
DME No. 2	Course Offset
Elevator Position	Flight Director Sensitivity
Aileron Position	Waypoint By Pass
Rudder Position	Event Marker
Elevator Trim	Marker Beacon
Indicated Airspeed	
Flap Position	**Warnings**
Throttle Position No. 1	VOR No. 1
Throttle Position No. 2	VOR No. 2
Propeller Speed No. 1	DME No. 1
Propeller Speed No. 2	DME No. 2
Torque Pressure No. 1	R-NAV Power
Torque Pressure No. 2	Radio Tuning
Bearing to Waypoint	Pressure Altitude
Distance to Waypoint	
Lateral Acceleration	
Vertical Acceleration	

Wind Study Instrumentation. A variety of wind measuring equipment was used and correlated with ADAS data, standard met reports, and pilot reports. These were as follows:

- Standard meteorology station U2A wind recorders situated on and around the STOLports for measuring surface winds,
- A U2A anemometer installed on a 60 meter mast located on the roof of the CIBC building in Montreal situated approximately 2 kilometers from the STOLport,
- A U2A anemometer installed on a 10 meter tower located on the roof of the Highlands Apartment approximately 1 kilometer from the Ottawa STOLport,
- A 33 meter portable tower from NAE set up at the Ottawa site to provide wind speeds and temperatures at four altitudes above the STOLport surface,
- A sonic anemometer and an acoustic sounder from AES,
- A Bell 205 helicopter provided by NAE that could measure and record instantaneous winds encountered by the helicopter as it flew down the approach path, and
- AES model of the Ottawa STOLport set up in a wind tunnel to try to correlate model results with full scale measurements.

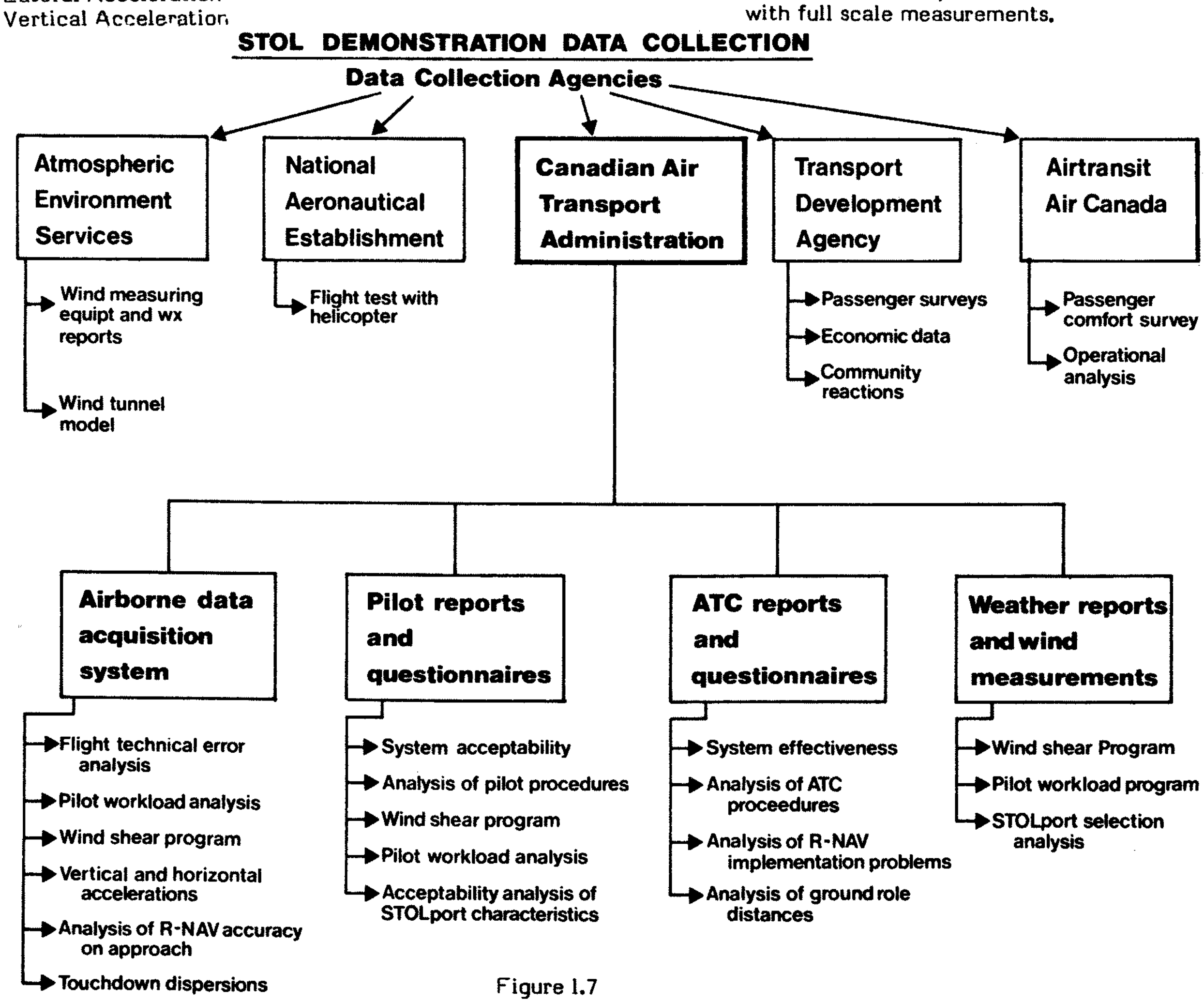


Figure 1.7

Questionnaires. A number of questionnaires were used to obtain ATC, flight crew and passenger opinions:

- Pilot workload study (Approach Weather Problem),
- Data Analysis Information Sheet - to provide crew information on aircraft loading, routes, weather, type of landing approach used, etc.,
- Pilot opinion on STOL procedures,
- Air traffic controller views of the system, and
- Passenger surveys conducted periodically by TDA.

PART II
SUMMARY OF FINDINGS

The following information is offered in the form of a brief explanation of the analysis with an emphasis on the findings and an interpretation of their relevance.

R-NAV in a STOL Environment

A three dimensional R-NAV profile was implemented to provide a number of benefits:

- reduce controller workloads,
- reduce radio congestions,
- add flexibility to the route construction,
- improve accuracy hence reducing airspace requirements, and
- provide an approach capability.

An assessment of how well these benefits were realized was obtained from the personnel involved - the operating pilots, the flight inspection pilots, the ATC controllers, and the airspace planners.

Routing. One factor of an R-NAV application to a STOL route structure was clearly established; the routes must be thoroughly planned to ensure a maximization of the potential benefits of R-NAV. The equipment could become a disadvantage when its flexibility is used to bypass the conventional protected areas. This disadvantage to the operator can however, be a benefit to the airspace planner. In order that a proper balance of benefits be attained between the operator and the regulatory agency, a priority use of the airspace system may have to be considered. This assumes that an increased efficiency in airspace useage warrants encouragement by the government for the use of R-NAV.

The pilots, controllers, and planners were unanimous in proclaiming the benefits of a three dimensional R-NAV profile as it was initially structured for the demonstration. When a less direct routing was later implemented, because of operational constraints in the Montreal area, the balance of benefits was tipped in favour of the planner. The operator was faced with longer routes than existing conventional airways, and the pilot/controller workloads and the radio congestion increased with a surge in enroute requests for more direct tracks.

Workloads. Generally it was found that pilot workloads decreased through use of R-NAV. There were, however, two exceptions;

- Initial set up and proving of the data, and
- A failure or loss of signal which could necessitate a reprogramming of the computer or reversion to conventional navigation.

The ATC controllers reported a significant reduction in their workload. It was found however, that it was possible for a controller to forget about the Airtransit aircraft since normally only a monitoring involvement was required.

Accuracy. The accuracy of the R-NAV system was measured and monitored by:

- initial flight tests using maps, radar and a separate computer to compare DME/DME calculations,
- periodic flight checks during the demonstration,
- observation by ATC terminal controllers, and
- Comparison with the MLS in the approach phase using ADAS data.

The route widths used in the demonstration were set at 4 nm (±2 nm). An assessment of the combined error tolerances for all of the contributing systems showed this width to be adequate for the complete route. Flight tests showed that the total lateral equipment error was ±.59 nm. Radar data showed that 90% of the observations were within .5 nm of the centerline.

Some problems were initially encountered in the computer logic caused by intermittent signal reception at low altitudes. Once this problem was eliminated by operational procedures, large navigational errors were negligable.

The accuracy of the R-NAV in the approach phase was computed by assessing the difference between the R-NAV track deviation and the MLS deviation. The confidence level of the results is therefore dependent upon the accuracy of the MLS signal. The accuracy of the R-NAV in the approach was highly dependent upon the geographic orientation of the reference stations. In good DME/DME geometry, the typical approach accuracy was less than ±.15 nm (95% probable) in the horizontal, and ±200 ft. (99.7% probable) in the vertical.

Development. It was recognized that navigation system sophistication was undergoing an extremely rapid development. This presented the possibility that the STOL R-NAV system criteria and procedures would be out-of-date before they were produced. A constant review of area navigation technology was therefore maintained. Concurrently, the contributing systems were assessed in order to determine the state-of-the-art error budgets that might be applied in accordance with the principles of a STOL concept (in this case minimizing the error potential in order that airspace useage and operational procedures could be optimized). Changes in R-NAV technology meant that operational procedures and criteria for assessing the system error had to be developed to cover all possible combinations of reference stations.

Vertical Navigation (V-NAV)

The vertical capability of area navigation was used to completely pre-program the flight profile. A clearance on an R-NAV route constituted an instruction to be at the designated altitudes for each of the waypoints. The vertical capability was also used on the R-NAV approach to present a six degree glidepath to R-NAV minimas.

The V-NAV function met with mixed success. It was discovered that the primary advantages were: reduction in controller workload and in radio congestion. The V-NAV system proved to be beneficial during the approaches as a back-up and reference to the MLS. Alternatively, many of the pilots tended to ignore the vertical command while enroute and would climb and descend conventionally using the vertical speed indicator and the altimeter.

The evidence shows that a very strong emphasis and efficient training system would be required before V-NAV could be used for separation in a vertical tube type arrangement.

Nevertheless, a potential for this type of system remains, hence the Project Team investigated procedures and protection requirements that could be applied to STOL route criteria. As an example, with an along track error of 2 nm the range of vertical protection recommended was approximately 2,000 feet on a 3° slope and to 4,000 feet on a 6° slope.

Flight Technical Error (FTE) Analysis

The flight technical error was defined for our purposes as the difference between the indicated command position and the indicated aircraft position. The value measured was the aircraft deviation from the center line as indicated by the Horizontal Situation Indicator (HSI).

The data came from a completely random selection of tapes taken from the 6 aircraft and forty-eight pilots. The tapes that were analysed came from a three month period of time when the weather is normally at its worst. There was no attempt, however, to select only bad weather days since it was considered more important to have values that reflect the type of probable error under all weather conditions. In order to ensure a consistency of the data, the summarized results were correlated with randomly selected tapes covering the remainder of the two year demonstration period. The analysis of this FTE was divided into four avenues of interest:

- deviation in the horizontal plane while enroute,
- deviation in the vertical plane while enroute,
- lateral deviation on the approach, and
- vertical deviation on the approach.

In addition to the analysis of the random selection of tapes, a study was conducted on data collected in the approach phase during days featuring turbulence or bad winds.

Horizontal FTE Enroute. The analysis of the lateral FTE in the enroute phase was conducted by statistically summarizing data for the complete route as well as the samples contained in each individual segment. The enroute phase was considered to encompass the entire route with the exception of the approach (i.e. it would therefore include the airspace inside the terminal area). The segment lengths ranged from two to twenty-one nautical miles. The computed values were correlated with many of the factors that would cause a predictable bias in the disposition of results. The influencing factors considered were:

- whether or not a turn was required when transitioning from the previous segment,
- angle of the turn,
- navigation mode (DME/DME or VOR/DME),
- navigation reference aid geometry,
- segment length, and
- location of the segment (i.e. vicinity of the airport, etc.)

The tapes used in the statistical summary represent nineteen thousand three hundred miles of flight. The two sigma (95% probable) deviation for all of the samples was ±.47 nm. This figure includes a very small bias which in our case was almost always to the left of centerline. The samples fit a Guassian distribution pattern as illustrated below.

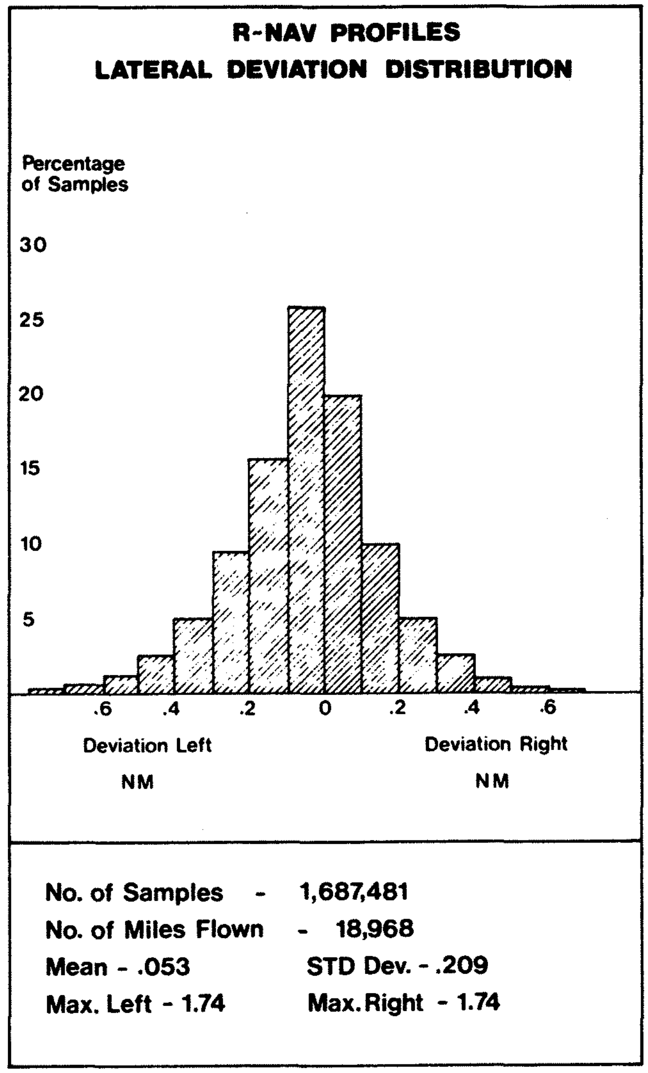


Figure 2.1

It was found that the deviations in the turns were smaller than expected, and that no pattern in the size of the deviation existed with turns ranging from 0 to 90 degrees. The small deviation in turns was attributed to the slow speed aerodynamic characteristics of the aircraft and the turn anticipation capability of the area navigation system. Turns greater than 90° (manoeuvring in the terminal area) showed large deviations and produced a non-normal statistical distribution.

The assessment of FTE as related to the navigation mode and reference aid geometry was conducted to compare the effect of an increased accuracy of the computed position. The results showed that there was no significant difference in FTE when using DME/DME and VOR/DME as long as both modes were functioning in relatively accurate geometry situations. Large FTE deviations were produced, however, when a navigation reference change was made either to or from poor VOR/DME geometry. This portion of the total FTE is not completely independent since it varies according to the accuracy of the computed position. It's effect upon the airspace to be protected will depend upon the airway or route width. The segment that produced the largest deviation, not attributed to a turn, had a 95% probable FTE of ±.78 nm. The geometry correlation showed that this segment was in relatively good VOR/DME geometry, but the previous segment was in a poor VOR/DME geometry area.

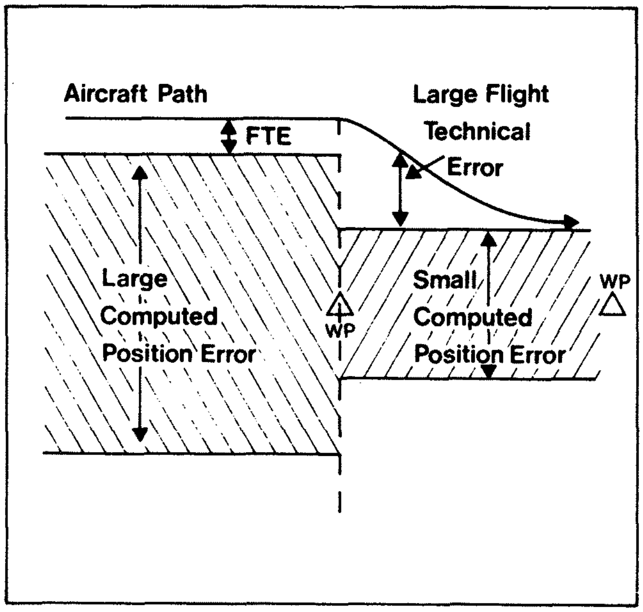


Figure 2.2

The longer segments generally produced tighter deviation values. This was attributed to a more stable guidance in the computed track due to the use of only one navigation reference combination and also due to the increased number of samples for that segment.

The results of a segment comparison analysis showed that there was no difference in the FTE for flight in the terminal area as compared to enroute segments. These results were produced despite an automation in navigation aid tuning and in the sequencing of cockpit information. It might therefore be concluded that one FTE value should be used for both inside and outside the terminal areas. The exception to this rule could occur when a less automated R-NAV system was used, resulting in a significantly increased workload and undoubtedly an increased FTE.

Vertical FTE Enroute. The procedure for analysing the vertical FTE in the enroute phase of flight was much the same as that for the lateral error. The major difference was found in the factors that might cause a bias in the results. The factors that were considered significant were:

- the slope of the segment,
- an ascending or descending segment,
- length of the segment, and
- location of the segment in relation to the terminal area.

A summary of all the relevent samples analysed (1,433,962) produced a FTE of ±156 feet, taken to a 99.7% confidence level and including a small bias on the high side. The deviation varied significantly according to the slope of the segment. The range of values is summarized as follows:

level flight	±115 feet
1° slope ascending	±200 feet
3° slope ascending	±185 feet
1° slope descending	±230 feet
3° slope descending	±380 feet

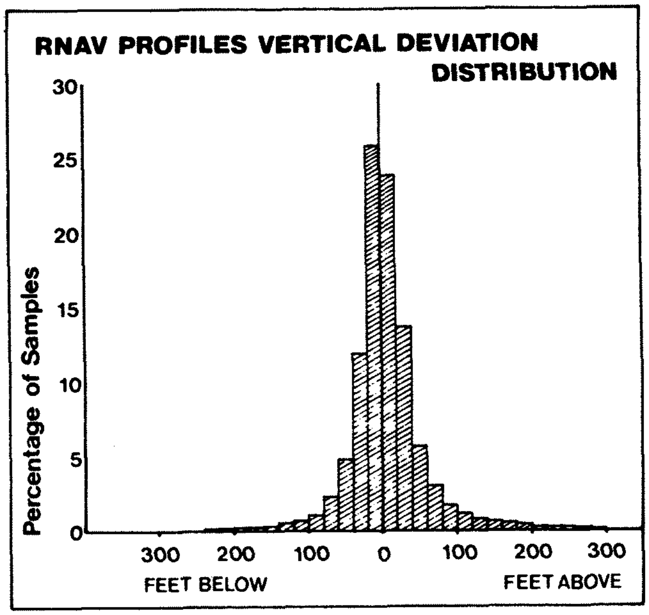


Figure 2.3

Overall, it was found that the deviation was higher in the descending segments than in the ascending segments.
Example:

descending	±260 feet
ascending	±210 feet

The longer vertical segments produced larger deviations, especially if one descending or ascending segment led into another.

The deviations in the vertical plane were found to be slightly larger in the vicinity of the terminal areas.

Lateral Deviation on Approach. The FTE analysis in the approach phase was conducted by separating the localizer into half-mile intervals. A summary was made and analysed thereby producing distributions in nautical miles from the centerline for each interval. The data for each aircraft and for each runway was also summarized.

As was expected, the FTE became smaller as the runway was approached. The following diagram shows how the 95% confidence limit for FTE was distributed between 4 nm and 1/2 nm from the runway. (DME distance, where the DME site is 1,000 feet down the runway from the threshold.)

The FTE at 1/2 mile was ±158 feet including an 18 foot bias to the right, and at 4 miles it was 1,145 feet including a 71 foot bias to the right. (The bias to the right was due to a 3° offset of the localizer from the runway centreline.)

Since the HSI sensitivity on one aircraft differed significantly from the others, the data for each aircraft was analysed individually in an attempt to correlate the HSI sensitivities with the FTE. Contrary to what had been expected the more sensitive HSI had the larger FTE.

HSI 1 dot = 1.5° FTE = ±.018 nm at 1/2 nm DME
HSI 1 dot = 1.17° FTE = ±.037 nm at 1/2 nm DME

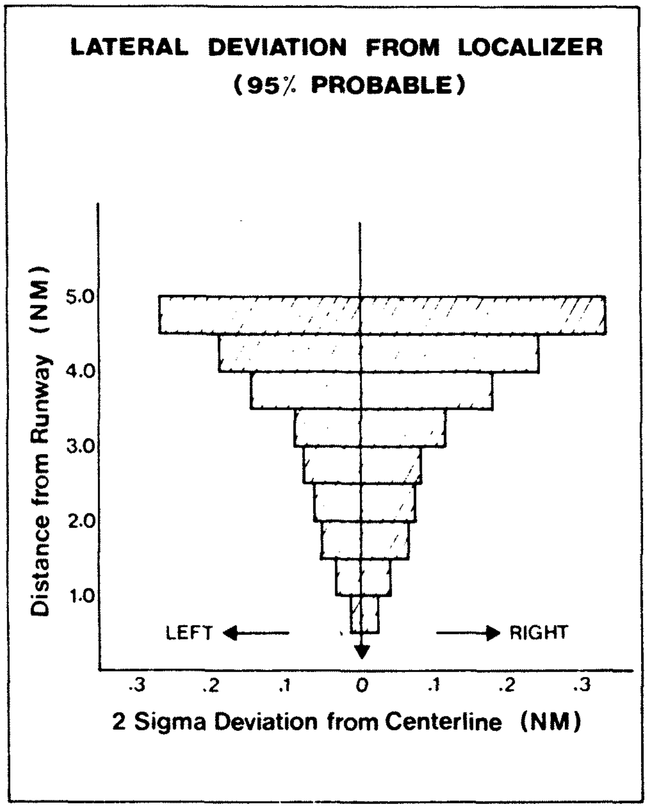


Figure 2.4

The separation of the data according to the runway enabled a correlation of the FTE with the alleged difficulty of the approach. For example, the approach to runway 24 at Montreal was considered extremely difficult to fly due to unpredictable wind shifts. The results showed that there was a significantly larger lateral deviation for approaches to runway 24.

Vertical Deviation on Approach. The analysis of the vertical FTE was conducted using the same procedures as those for the lateral error. The value of FTE was determined to a 3 sigma accuracy (99.7%). The deviation at 1/2 nm was±48 feet and at 4 nm it was±163 feet.

The relationship of the HSI sensitivities were correlated in the vertical as had been done with the lateral. In this case, the most sensitive HSI produced the smallest error.

HSI 1 dot = .8° FTE was ±52 feet at 1/2 nm DME
HSI 1 dot = .5° FTE was ± 35 feet at 1/2 nm DME

The correlation of the individual runways showed that the difficult approach on Runway 24 at Montreal produced a significantly higher FTE than the other runways.

Touchdown Point Dispersion

The effectiveness of a landing system can be assessed through analysis of the touchdown point of many landings observed during normal flight operations. This takes into consideration the aircraft handling and performance characteristics, the approach guidance system, the instrument presentation to the pilot, the pilot's ability to control the aircraft and finally, the effect of weather.

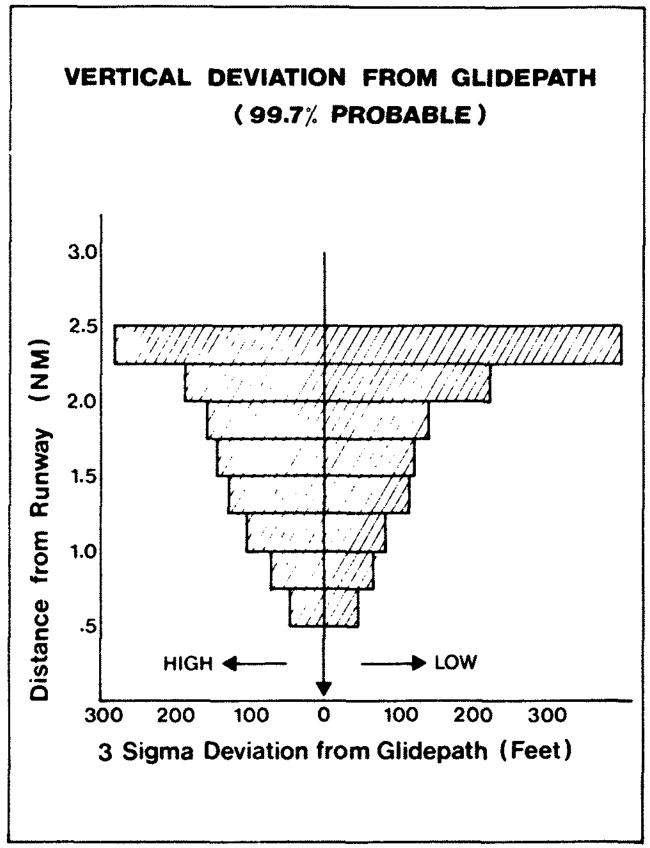
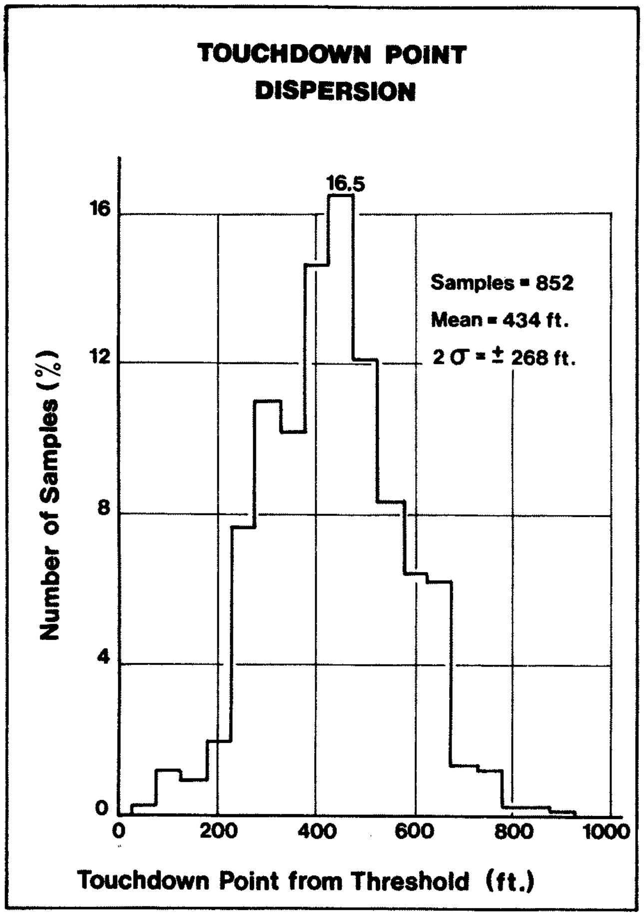


Figure 2.5

From the data recorded by the ADAS, the touchdown point on the runway was calculated and landings which were considered to be representative of the operation were analyzed. The results are given in figures 2.6 and 2.7. There was a correlation between touchdown point and the following factors;

- the aircraft touched down closer to the threshold as the headwind component increased for moderate to severe turbulence conditions. The trend was reversed for light turbulence,
- as air turbulence increased the aircraft touched farther down the runway,
- the aircraft touched down in the center of the target area when the winds were calm or light, and
- the position of the taxiways relative to the normal ground roll distance influenced the touchdown point.



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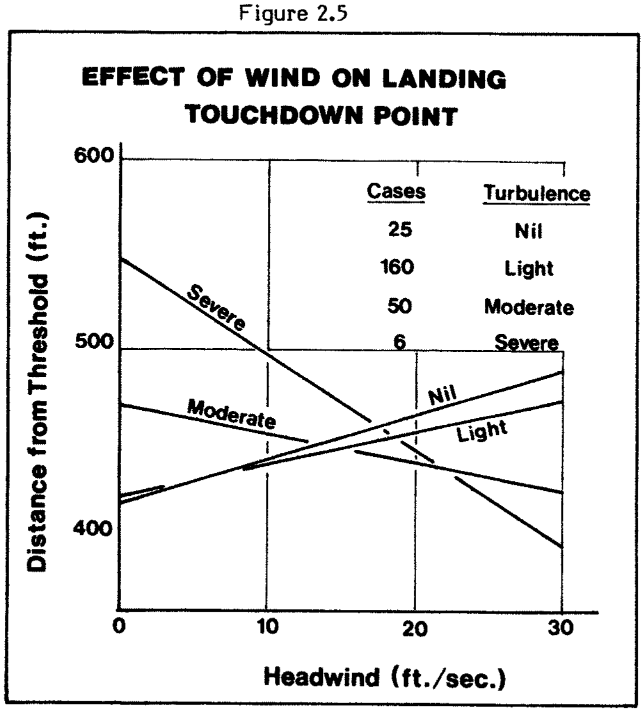

Figure 2.6

<u>Landing Ground Roll Distance</u>

The ground roll distance was determined from 241 landings made on runway 24 at Montreal. With this runway, the aircraft had to make a 180° turn after landing to taxi to the terminal, therefore it was assumed that a true value of the distance represented by the aircraft capability and crew handling would be obtained. The results are given in figure 2.8.

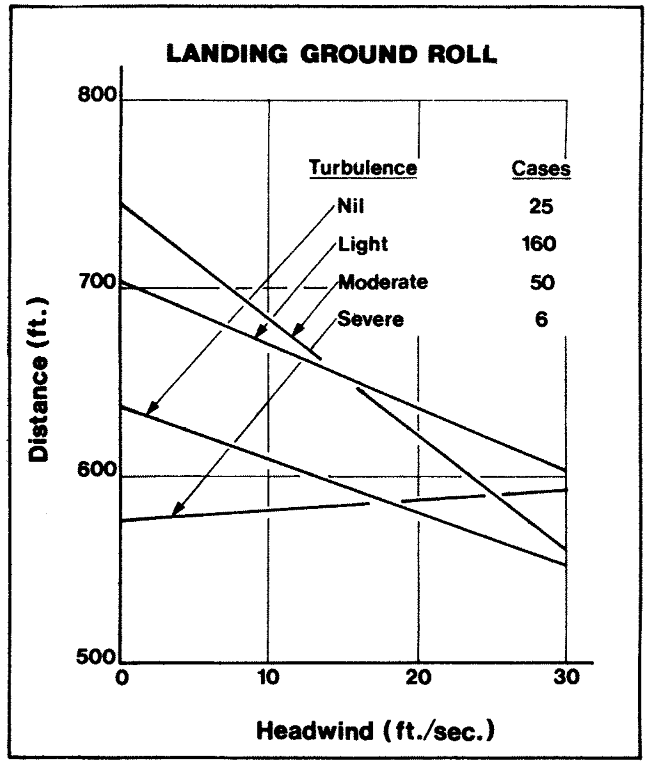

Figure 2.8

<u>Height Dispersion Over the Threshold</u>

Thirty-eight landings made on all runways were analyzed to determine the height of the aircraft as it crossed the runway threshold. The results are given in Figure 2.9.

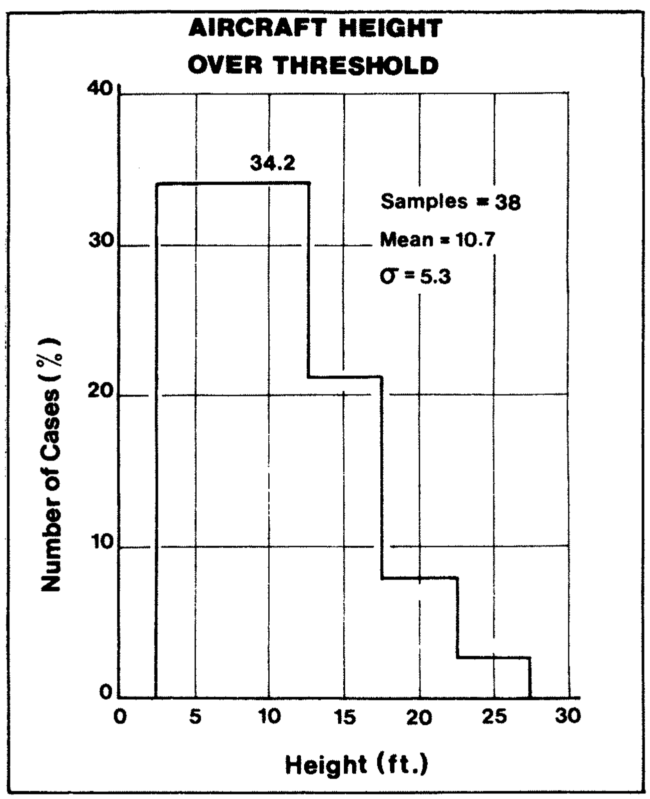

Figure 2.9

Airspeed Dispersions

The airspeed of the aircraft was analyzed for 36 approaches at 35 feet above touchdown point, and as the aircraft crossed the runway threshold. The results are given in table 2.1

APPROACH SPEED VARIATION OVER THRESHOLD AND AT 35 FT. SCREEN HEIGHT

Headwind ft./sec.	Threshold ft./sec. True			35 ft. Screen ft./sec. True		
	No.	Mean	σ	No.	Mean	σ
0 - 10	14	107.8	13.6	14	107.7	13.7
10 - 20	14	117.7	13.3	15	117.8	12.7
20 - 30	4	127.6	9.9	4	127.2	9.9
30 - 40	4	132.7	13.1	4	131.2	13.0

Table 2.1

Normal and Lateral Accelerations

Normal and lateral accelerations were measured from the fall of 1975 through to the end of the demonstration. Seven flight hours have been analysed so far to give accelerations in level flight at several altitudes. The results, are given in figures 2.10 and 2.11 in terms of the number of hours of flight required before an acceleration is experienced that equals or exceeds a given value above or below the 1g level flight value.

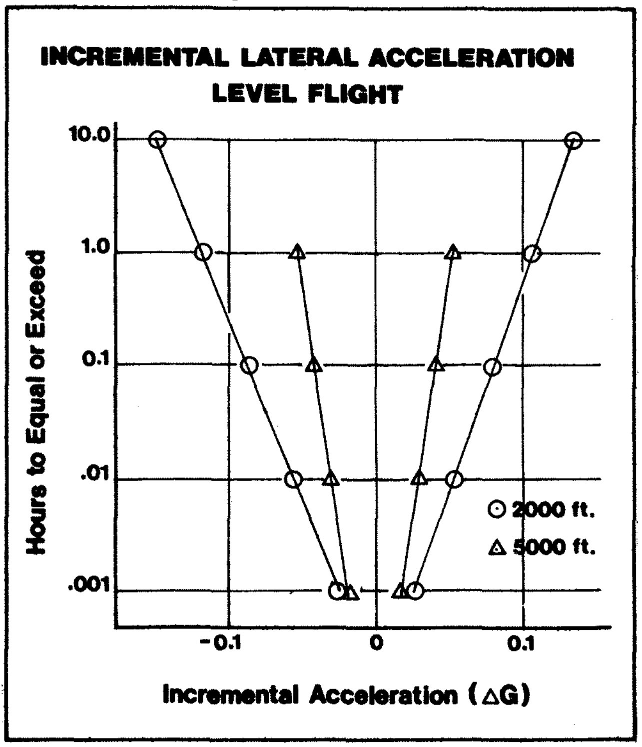

Figure 2.10

In addition to the "Hours to Exceed" study, several tapes containing a total of 9 flight hours are being analyzed through the courtesy of the National Aeronautical Establishment to provide a "Spectral Density" picture of the accelerations experienced. The results of this work were not available at the time of writing.

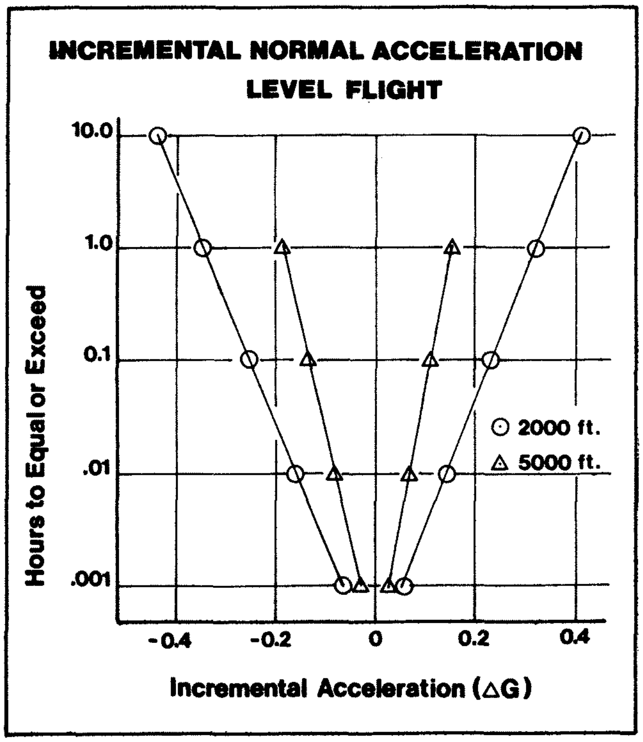

Figure 2.11

Wind Shear, Turbulence and Crosswind

Wind shear, turbulence and crosswinds are expected to be more severe at a STOLport because of the constraints of runway alignment and land area available and also because of the physical influence of the nearby structures near a downtown STOLport. Because of the low climb and approach speeds for STOL aircraft in relation to CTOL passenger aircraft, the wind conditions are of significantly greater importance. Consequently a program was undertaken to monitor the wind conditions at the STOLports, and obtain comments from the flight crews as to the effect that the various measured characteristics had on the crew workload. In addition, a model of the Ottawa STOLport area was studied in a wind tunnel and compared with the data measured at the STOLport in the hope that this may prove helpful during STOLport site selection. This work was being done for MOT by the Department of the Environment and at the time of writing, the results were not available.

Wind shear has been identified as an important consideration in the safe operation of CTOL aircraft particularly in the landing phase. This is expected to be even more important in STOL operations. Therefore much of the Wind Program concentrated on the problem of wind shear. Figures 2.12 and 2.13 show two samples measured by the NAE helicopter while flying the approach path at the Ottawa STOLport.

It is interesting to note that, although by definition, the shear of February 24, 1976 was large the pilots hardly even noticed it. This is probably due to the fairly uniform change with altitude. On the other hand the shear measured on March 9, 1976, caused the crew considerable difficulty in maintaining the approach path.

The effect of crosswinds turned out to be extremely important and resulted in Airtransit instituting the use of partial flap as crosswind components approached the 18 to 22 knot values with a maximum tolerable value between 25 and 30 knots.

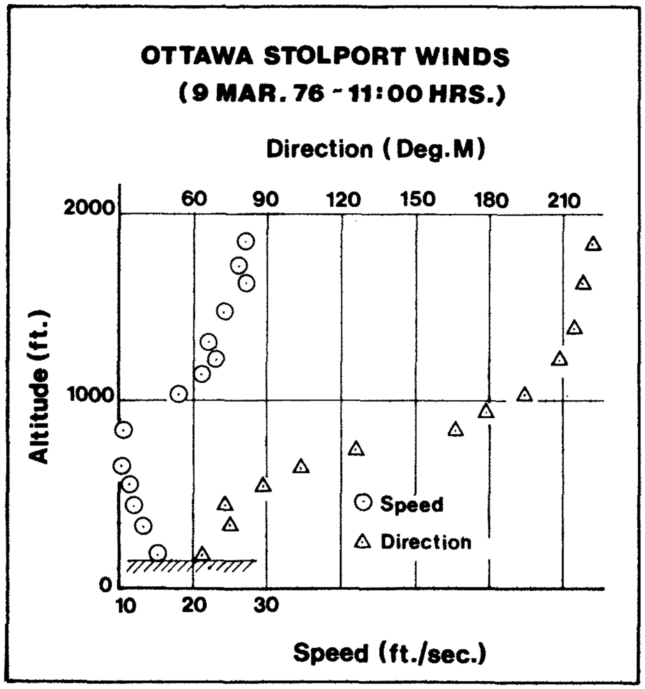

Figure 2.12

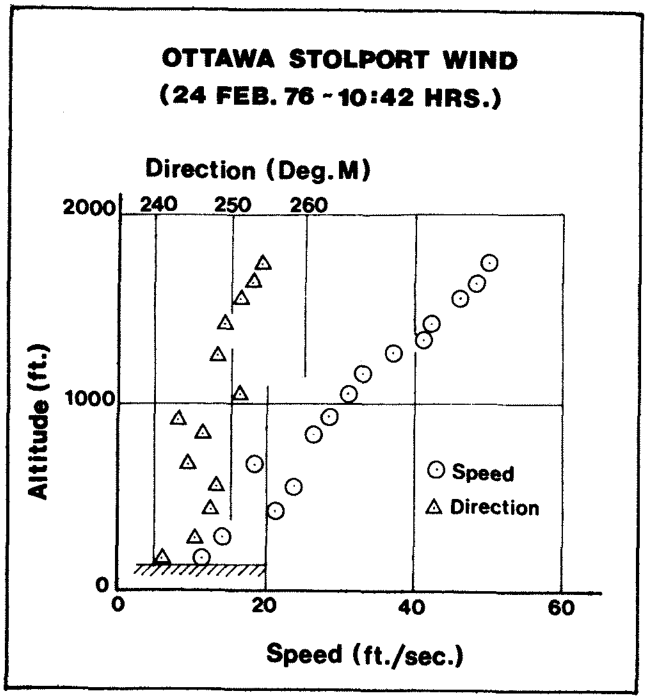

Figure 2.13

PART III
APPLICATION OF FINDINGS

The results of the data analysis exercises are being applied to structure recommendations designed to achieve the objectives outlined in the introductory remarks. The specific recommendations are featured in the following reports:

- STOL R-NAV Route Criteria,
- STOL Approach Criteria,
- Operating Procedures and Navigation Performance Standards,
- STOL Zoning Requirements, and Airworthiness Requirements for STOL Aircraft and Airborne Equipment.

STOL R-NAV Route Criteria

An inter-city STOL concept incorporates a number of parameters that influence the design of its functional systems. These include:

- short runways,
- steep approach angle,
- steep departure climb angle,
- frequent service,
- efficient, fast service (minimization of delays).
- minimization of land requirements, and
- minimization of airspace requirements.

In terms of an R-NAV route between two STOLports, these parameters can be reduced to:

- minimization of route lengths,
- minimization of airspace requirements, and
- minimization of delays caused by traffic congestion.

STOL R-NAV route criteria were developed with the philosophy that the constraining factors would be different at each location. It was therefore necessary to structure a system that could be adjusted to the needs of the area and yet retain the principle of standardization. A heirarchy was developed for the sophistication and capability levels of navigation equipment. These levels were then categorized in the form of navigation performance standards upon which the "airspace to be protected" could be defined.

The experiences gained from the Ottawa-Montreal demonstration were used to develop a matrix of requirements for each of the categories. The middle-of-the-road system is modeled from the demonstration with some up-dating allowed by technological advances. The advanced system reflects the capabilities of modern air carrier navigation equipment, and the lower level system reflects basic IFR equipment.

The system consists of a basic 4 nm route width, a method for proving the width within the accuracy requirements of the available navigation aids, and a procedure for expanding the width if the error tolerance is not adequate. Similarily a methodology was developed to provide protection in the turns to supplement the basic width, and a holding protection area was defined appropriate to the slow speed characteristics of STOL aircraft. A vertical airspace requirement was developed for the sloping segments with the understanding that it should only be applied when a benefit could be derived and with a very thorough training of the aircrew.

Many lessons were learned prior to and throughout the demonstration relating to airspace planning and ATC procedures. These experiences were applied to developing a checklist of items that should be considered when constructing a route. Similarly the ATC procedures used in the demonstration are being revised to reflect recommendations made by the controllers and the pilots.

STOL Approach Criteria

Many of the elements of the system that provided over twenty-four thousand safe landings have been incorporated into the approach design. Criteria are to be established for the following procedures:

- MLS precision approach,
- R-NAV non-precision approach, and
- R-NAV missed approach.

The ruling principle in the development of the STOL approach criteria was "standardization". This rationale was not adopted to restrict the advantages inherent in the flexibility of MLS or R-NAV. It was instituted to prevent a large amount of non-uniformity in procedures and aircraft handling techniques which could compromise flight safety. The criteria is designed such that one standard format would be established and subsequently implemented wherever possible. When the established procedure could not be accommodated, the flexibility of MLS and R-NAV could be used to develop a non-standard approach.

An MLS approach established at an angle of 6°, was confirmed as the standard precision instrument approach designed to satisfy the parameters of a STOL system. The 6° glidepath, as used in the demonstration, was assessed by the AIRTRANSIT pilots as the maximum they would prefer to see using a DHC-6. The Twin Otter and the De Havilland Dash-7 were both considered as potential users of inter-urban STOL systems, both of which could safely operate on a 6° glidepath.

The R-NAV approach criteria is presented primarily as a non-precision back-up system to the MLS. The R-NAV is designed as the primary but not the only means by which the MLS localizer can be captured.

The criteria developed for the missed approach is based on the use of area navigation as the means of guidance.

Operational Procedures and Navigation Performance Standard

If the advantages of a decreased airspace requirement are to be realized, a certain standard of equipment and operating capability must be established. The philosophy of categorizing a navigation performance standard was discussed earlier in relation to the route criteria. The "Operational Procedures and Navigation Performance Standard" manual is designed to specify in more exact terms what is expected of each level of performance standard.

The three categories of navigation performance standard are designed such that the basic category is compatible with general aviation pilot abilities. The two more advanced categories require a higher level of professional skill and experience. The crew capabilities and levels of training must be comparable to those existing in the demonstration in order that the applicable F.T.E. figures are valid. The operational procedures and the pilot initial and re-current training requirements are therefore specified where applicable in order that the enroute and terminal criteria would not be violated.

The functional requirements of the navigation equipment are outlined for each category, as are the total equipment accuracy specifications. For example, each category of equipment standard dictates the minimum requirement in terms of;

- mode of operation,
- V-NAV capability,
- automatic slant range correction,
- turn anticipation,
- data input requirements,
- waypoint storage,
- method of data input, and
- information and status displays.

STOLport Characteristics

Generally the design and construction of the STOLport would coincide with the needs of the area, and the type of operation envisaged. There are, however, a number of characteristics that should be standardized to provide for planning guidelines and operational uniformity.

The STOLport zoning criteria are being developed using, as a base, typical STOL aircraft performance capabilities in conjunction with the data and experiences gained during the demonstration.

The lighting systems designed for the demonstration STOLports were assessed and the concluding information was used to make recommendations for a standard format. Similar analyses were conducted on the typical elements of a STOLport such as runway lengths and widths, taxiway widths, obstruction marking, and surface clearance requirements.

Airworthiness Requirements

The airworthiness requirement recommendations are not a comprehensive set of requirements and are to relate only to a STOL system that uses an aircraft employing a high lift design philosophy similar to the Twin Otter. It is recognized that the current standard of airworthiness for transport aircraft and airborne equipment must be at least maintained. In most of the design areas these requirements are also valid for a STOL aircraft and any suggested changes would be additions reflecting a change in emphasis rather than a radical change in concept. In several design areas the data is to substantiate that the current requirements are adequate and that no additional considerations are necessary.

The areas that are affected most are the flight handling characteristics and the performance information. Special attention is being paid to the capability of the aircraft to fly a steep approach, to handle wind shear, cross wind and wind turbulence. The use of drag and lift control devices are considered important and the determination of satisfactory pilot procedures and the associated margins relating to airspeed, angles of attack, reserve thrust, etc., are receiving a high priority.

Because it will be necessary to fly the aircraft at its maximum capability to achieve the short runways that make STOL attractive more factors affecting performance must be determined accurately during the Type Approval testing with rational operational factors applied to the values obtained under carefully designed and skillfully conducted company tests. This implies that the flight planning and dispatch for a specific flight will become more comprehensive at the airline level.

CONCLUSIONS

The Air Data Acquisition System provided a data base of over 3,800 recorded flights upon which the STOL Project team was able to conduct many valuable studies. The potential of the data was, however, by no means exhausted. The data is being retained in the National Archives upon conclusion of the present work and will be available to manufacturers and researchers for further study.

Technically and operationally the Ottawa-Montreal STOL Demonstration was successful. The criteria, procedures and requirements that characterize a STOL operation have been or are being developed such that the Canadian Air Transportation Administration will be better prepared for a future implementation of STOL transportation networks.