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NASA-CR-165,673

NASA Contractor Report 165673

NASA-CR-165673
1981 0013502

CANDIDATE CDTI PROCEDURES STUDY

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CONTRACT NAS1-16247
JANUARY 1981

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NF02184

TABLE OF CONTENTS

Table of Contents	i
List of Figures	iv

Section	Page
1.0 BACKGROUND	1-1
2.0 STUDY PARAMETERS	2-1
2.1 Technological Environment	2-1
2.2 Aviation Growth Rates Applied to Technology Environment	2-2
3.0 CDTI CANDIDATE PROCEDURES	3-1
3.1 Merging	3-2
3.1.1 Potential Application	3-2
3.1.2 Procedural Concept	3-2
3.1.3 Typical Merging Procedure Display	3-3
3.1.4 Typical Minicontract Clearance	3-3
3.1.5 Operational Considerations	3-5
3.1.6 Comments	3-5
3.2 Spacing	
3.2.1 Potential Application	3-5
3.2.2 Procedural Concept	3-6
3.2.3 Typical Spacing Clearance	3-6
3.2.4 Typical Spacing Procedure Cockpit Display	3-6
3.2.5 Operational Considerations	3-9
3.2.6 Comments	3-10
3.3 Parallel Approaches To Closely Spaced Parallel Runways	3-11
3.3.1 Potential Application	3-11
3.3.2 Procedural Concept	3-12
3.3.3 Typical Display	3-17
3.3.4 Typical Clearance	3-17
3.3.5 Operational Considerations	3-17
3.3.6 Comments	3-18

N81-22032#

TABLE OF CONTENTS
(Continued)

Section		Page
3.4	Dual Approach Paths To A Single Runway	3-19
3.4.1	Introduction and Comments	3-19
3.5	Multiple Curved Approach Paths	3-20
3.5.1	Potential Application	3-20
3.5.2	Procedural Concept	3-22
3.5.3	Typical CDTI Display	3-26
3.5.4	Typical Approach and Landing Clearance	3-26
3.5.5	Operational Considerations	3-26
3.5.6	Comments	3-28
3.6	Cockpit Monitoring Of Runway Environment	3-29
3.6.1	Potential Application	3-29
3.6.2	Procedural Concept	3-30
3.6.3	Typical Runway Environment Display	3-31
3.6.4	Typical Clearance	3-33
3.6.5	Operational Considerations	3-33
3.6.6	Comments	3-34
3.7	Missed Approaches	3-34
3.7.1	Potential Application	3-34
3.7.2	Universal Missed Approach Considerations	3-35
3.7.3	Parallel Approaches To Closely Spaced Parallel Runways	3-36
3.7.4	Dual Approach Paths To A Single Runway	3-38
3.7.5	Multiple Curved Path Approaches	3-38
3.7.6	Procedure Adaptation To The Local Environment	3-42
3.8	Route Crossings	3-43
3.8.1	Potential Application	3-43
3.8.2	Procedural Concept	3-44
3.8.3	Typical Route Crossing Procedure Display	3-44
3.8.4	Typical Crossing Clearance	3-46
3.8.5	Operational Considerations	3-46
3.8.6	Comments	3-46

TABLE OF CONTENTS
(Continued)

Section		Page
3.9	Weather Avoidance Deviation	3-47
3.9.1	Potential Application	3-47
3.9.2	Procedural Concept	3-48
3.9.3	CDTI Weather Deviation Clearance	3-48
3.9.4	Typical Weather Deviation Display	3-39
3.9.5	Operational Considerations	3-49
3.9.6	Comments	3-51
4.0	DISPLAY CHARACTERISTICS	4-1
4.1	Merging Display	4-1
4.2	Spacing Display	4-5
4.3	Ground Monitor Display	4-7
4.4	Flight Phase Selector	4-10
5.0	RECOMMENDED PROCEDURAL TEST SEQUENCING	5-1
6.0	SUMMARY	6-1
BIBLIOGRAPHY		B-1

LIST OF FIGURES

Figure		Page
3.1	CDTI Merge Display	3-4
3.2	CDTI Spacing Display	3-8
3.3	Accordion Effect Enroute	3-9
3.4	Accordion Effect Terminal Area Modification	3-10
3.5	Dependently Controlled Parallel Approaches	3-14
3.6	Independently Controlled Parallel Approaches	3-16
3.7	Multiple Curved Approach Path Structure	3-23
3.8	Ground Monitor Display	3-32
3.9	Parallel Approaches To Parallel Runways	3-37
3.10	Parallel Approach To A Single Runway	3-39
3.11	Multiple Curved Approach Path Structure	3-40
3.12	Route Crossing	3-45
3.13	Weather Avoidance Deviation	3-50
4.1	CDTI Merge Display	4-2
4.2	CDTI Spacing Display	4-6
4.3	Ground Monitor Display	4-8

1.0 BACKGROUND

The current development of the CDTI concept has created the potential for increasing total airport capacity without compromising safety. This potential is believed applicable to the major airline hub facilities which are operating at or near capacity during peak traffic hours using current ATC operating procedures. The constantly increasing traffic demand at these facilities requires that new operating procedures be developed which will relieve traffic pressures without derogating flight safety. Historically, several promising concepts have been investigated which could potentially alleviate this problem in the short term. Long term alleviation is dependent on a combination of these concepts integrated with the effective utilization of related emerging technological concepts, such as the CDTI concept.

The term airport capacity is, in fact, a measurement of total approach and departure capacity. Because of the nature of the dynamic system, the actual limiting factor to current airport capacity is approach capacity. During the departure phase, aircraft acceleration increases the inflight spacing between aircraft in trail, while during the approach phase, deceleration tends to decrease the spacing. For this reason this report will concentrate on the development of procedures to increase approach capacity, although recommended enroute procedures will also be addressed.

Approach capacity, a function of aircraft final approach separation standards for conflict avoidance, is affected by many factors. The three which are the most important in today's system are as follows:

- Avoidance of Wake Vortices From Preceding Aircraft
- Runway Occupancy Time
- User Acceptance of Capacity Enhancement Techniques

Other factors influencing approach capacity are:

- Variable Final Approach Speeds Between Aircraft
- Maintainance of Acceptable Go-Around Rates
- Resolution of Potential Go-Around Conflicts
- Communications Capacity

- Community Relations Impact
- Navigation Signal Interference

The development of operational procedures to effectively utilize the potential advantages of a CDTI system should minimize the effect of many of these factors. Research is currently being accomplished on Vortex Advisory Systems and the overall wake vortex problem and this research should lead to effective means of eliminating or reducing the effect of this phenomena on final approach spacing. Thus, Runway Occupancy Time (ROC) and user acceptance delineate the direction which must be followed to effectively utilize the CDTI potential. Studies have shown that user acceptance is based on maintaining or improving current safety standards, positive conflict avoidance, and a reduced potential for, and positive control of, go-around situations. Runway Occupancy Time (ROC) is a quantitative function based on the safety standard that two aircraft (either takeoff or landing phase) cannot occupy the same runway at the same time. This is a reasonable standard and it should be maintained in the interest of not compromising safety. It has been suggested that ROC, and consequently final approach spacing, can be reduced in the current system by the use of high speed access and exit taxiways. It has also been shown that pilot motivation for reducing ROC is a significant factor at many airport locations. Mean ROC figures for given airlines show a strong correlation with the positioning of their passenger gate complex. Many pilots will use an earlier runway exit if it is compatible with their gate assignment. The introduction of additional pilot motivational factors should have a positive effect in reducing overall ROC.

Although these considerations should reduce ROC, and consequently increase airport capacity, at many locations larger gains may be achieved by the implementation of procedural innovations which will be made possible by the introduction of operational CDTI instrumentation into the ATC system. By including the pilot in the overall situational awareness loop, the introduction of closely spaced parallel runways may be feasible, and thus, may effectively double airport capacity based on current ROC standards. This theoretical doubling is of course

dependent on the development of final approach procedures which effectively utilize the dual runway potential while affording no compromise to current safety standards. Procedures which should be considered are:

- Dual approach paths with staggered dependent spacing
- Dual parallel approaches which are speed segregated and operate independently
- Multiple curved approach paths to common short final approach paths for each runway
- Speed segregated multiple approach paths

Although the concept of two closely spaced parallel runways has been previously considered, it is the advent of the CDTI concept and the inherent added safety feature it provides which may make this type of parallel runway operation feasible.

Because of its quantitative nature, ROC reduction is relatively straighforward and the procedures developed can be tested in a direct and quantitative manner. Likewise the incorporation of most metering and spacing principles and procedures (such as accurate high fix metering, delay fans, and trombone base turns) can be introduced and measured directly. User acceptance, however, is a qualitative factor which will be much harder to evaluate. Past studies have indicated that user concerns center primarily on safety considerations. Of primary concern, particularly in a reduced spacing environment, is the increased potential for low altitude go-around situations. Reduced spacing to a single runway using current procedures will necessarily increase this potential because of the increased possibility of reaching the go-around decision point before the preceding aircraft has cleared the runway. Dual runways should reduce this problem. Concern has also been voiced as to the communications capacity of the current system. With reduced spacing increased communications will be required. Under these conditions the capability to broadcast a go-around command may not be immediately available. Operational procedures (such as discrete aircraft frequency utilization, single go-around command frequencies, and approach light signaling) could be considered. In addition to the

objections raised in relation to go-around situtations, users have voiced concern with the possibility of navigation signal (ILS) interference and the radar discrimination of closely spaced aircraft. Operational experience at San Francisco International, where the runway and navigational aids configuration currently lends itself to difficulties of this nature, has indicated that signal interference and radar return garbling presents little or no impact on the orderly operational traffic flow. The qualitative nature of user acceptance requires that these aspects be further investigated however.

The effective utilization of the potential inherent in the CDTI concept must be developed through the testing of new procedural concepts. The inclusion of the pilot in the electronic situational awareness loop allows procedural operations which may provide large gains in overall terminal capacity without compromising aircraft safety.

The CDTI Program is a joint NASA/FAA research effort to investigate the potential application of providing traffic information in the cockpit. The specific objective of this study is to develop a set of candidate operational procedures, emphasizing the application of CDTI, which in turn can be used to support the NASA part-task simulation studies.

2.0 STUDY PARAMETERS

2.1 TECHNOLOGICAL ENVIRONMENT

All studies which deal with the design and development of realistic procedural concepts must define the environment in which those concepts will be implemented. This is particularly true when the environment is as technologically dynamic as the U.S. Air Traffic Control (ATC) system is. Computerization techniques are rapidly changing the nature of monitored control functions in the National Airspace System(NAS). Flight management computers have the potential to significantly reduce cockpit workload levels while increasing the functional output of the pilot. Implementation of other programs, currently under research and development by NASA and the FAA, will promote the effective utilization of the available airspace. Although the final direction in which the ATC system will eventually evolve is not completely known at this time, there are some basic principles which can be applied to future system definition. These principles will be the basis for the parameters and environmental constraints upon which this study rests.

In order to restrict the scope of this CDTI procedures study within workable limits, it was necessary to identify discrete locations along a continuum of technological implementation rather than a time referenced continuum. Ultimately two locations were chosen, arbitrarily termed near term ATC system and future ATC system. The near term environment was defined as similar to today's environment with implementation of only those advances required to make the CDTI concept available and practical. These advances include some type of data link capability for rapid information transfer between the ground and the aircraft (or some suitable airborne sensor), the establishment of incentives for motivationally reducing runway occupancy times, and the development of a reliable, real-time wake vortex warning capability. All other aspects of the near term system remain the same as those found in the ATC system in use today. Although not specifically time referenced, the near term system can probably be expected to occur within the next five years.

Technological definition of the far-term or future system proved to be more difficult. For the purposes of this study, technological criteria were limited to those improvements which related directly to the CDTI concept and its effective utilization. Specific criteria include:

- DABS data link
- ATC recomputerization
- Metering and spacing
- Area Navigation
- Advanced flight management computers
- Microwave landing system
- Satellite navigation system (GPS)
- Improved final approach monitoring system
- Automated Traffic Advisory and Resolution Service (ATARS)

Most of these criteria are currently in the planning and development cycle and final operational implementation is not assured. It is probably unlikely that all of them will become part of the ATC system at any time in the future. Specific CDTI procedures often can be related to specific ATC system improvements, however. Thus the future ATC environment definition relates specifically to that proposed procedure which is being discussed and the potential increased effectiveness which may be obtained from the developing technology. This definition maintains the flexibility required to consider the effect of, often times, diverse developing technologies on specific procedures without creating a set environment which will never reflect reality in total. Thus, the future ATC environment, as defined for this study, consists of a changing intermix of developing technologies projected into operational implementation in some future time frame with particular emphasis placed on those improvements which can directly complement the CDTI concept.

2.2 AVIATION GROWTH RATES APPLIED TO TECHNOLOGY ENVIRONMENTS

Two technological environments have been defined for the purposes of this study, the near-term and the future. These environments, rather than time referenced, were defined in relation to the implementation of

of specific technological advances. Growth rates, on the other hand, are traditionally presented as percentage increases per year. Direct integration of these two measures would be unrealistic and non-productive. Therefore, for the purposes of this study, the near term environment is considered to consist of the particular aircraft mix which is currently in operation in the NAS. In determining the specific values of this mix, statistics from the site being modeled should be of primary concern. For future environment mix determinations, traditional growth rates should be applied to the model site statistics while considering any local restrictions, regulations, or policies which may influence the projected aircraft mix. Time frames must be independently estimated based upon expected techonogical development and implementation time schedules. Although this technique does not specifically identify the physical airspace environment on a strict time-related schedule, it does provide the flexibility to adapt to changing time schedules and specific modeling localities.

3.0 CDTI CANDIDATE PROCEDURES

Although the CDTI concept has the potential for increasing the flow of meaningful traffic information into the cockpit during all phases of inflight operation, there are specific roles it may play to enable the development of a distributed management ATC system. This section will define those roles and will present the design of specific inflight procedures which can be operationally tested for potential integration into the ATC system. The specific roles includes:

- Merging
- Spacing
- Parallel Approaches to Closely Spaced Parallel Runways
- Dual Approach Paths to a Single Runway
- Multiple Curved Approach Paths
- Cockpit Monitoring of Runway Environment
- Missed Approach Procedures
- Route Crossings
- Weather Avoidance Deviations

These roles can be logically broken down into three categories: Basic procedural roles, approach roles, and enroute roles. Merging and spacing are the basic procedural roles, as they can be considered to be simple CDTI functions which will be the basis or building block for more complex enroute and approach procedures.

Every attempt has been made to base the procedures developed for this study, in their final format, on practical realities and aircraft safety considerations. Several potential roles were discarded early in the study because of their impracticality or lack of beneficial utility in improving the ATC system. These roles include passing lanes for aircraft on straight-in final approach and the use of CDTI in maintaining separation during random non-standard RNAV routing operations. As the concept is further developed, new applications for CDTI technology will undoubtably be uncovered. These applications should be investigated more fully at that time with emphasis on practicality and safety considerations. It is hoped that these initial

procedures contained in this study will aid in furthering CDTI concept development.

3.1 MERGING

3.1.1 Potential Application

The use of the CDTI for the merging of an equipped aircraft into an existing aircraft stream is particularly applicable during the enroute and initial stages of terminal area phases of flight. It could also be adapted for use during the final approach phase in a low density environment. The merging role can be an independent operation or it can be adopted to be an integral part of a larger-scoped operation such as a multiple curved path approach using MLS. Of all of the potential CDTI procedural applications, the merging role will prove to be one of the most beneficial in terms of capacity enhancement and flight safety.

3.1.2 Procedural Concept

The merging process, regardless whether it is accomplished by a ground controller or through inflight instrumentation, is dependent on two parameters, the availability of a vacant position in the stream for the merging aircraft and the successful movement of that aircraft to the vacant position. In order to do this, the merging aircraft must temporarily change his navigational point of reference to the aircraft upon which he is joining. For ease of interpretation this should be the aircraft directly in front of his intended position in the stream. All clearances should reflect this point of reference and be given as a distance (separation) behind the "lead" aircraft. Additionally altitude separation should be maintained throughout the merging maneuver until lateral position is reported by the pilot and confirmed by the ground controller.

Clearance to perform the merging maneuver would be given in the format of two sequential minicontracts, the first of which would allow lateral merging with altitude seperation and the second of which would allow vertical merging. Once the aircraft is in the desired position laterally and the pilot reports this, the controller confirms his position,

cancels the first minicontract, and issues a second which enables vertical merge. The successful completion of this contract terminates the merge procedure.

As an optional aid to intercepting the desired lateral position in the stream it is recommended that command heading information derived from an on-board computer solution be presented on the CDTI display.

3.1.3 Typical Merging Procedure Display

A possible CDTI merging display is depicted in Figure 3.1, showing a potential merge of the aircraft labeled "2" (ownship) between aircraft "1" and aircraft "3". The desired final positioning is indicated by the intersection of the reciprocal track of aircraft "1" and the arc of desired separation distance using aircraft "1" as the point of navigational reference. The optional command heading indicator is depicted in the lower right hand corner of the display. Manual heading computation can be determined by maintaining a heading which keeps the desired position at a constant relative bearing to ownship throughout the intercept. This manual intercept procedure precipitates more pilot workload and involves an initial trial and error concept for its utilization, but it can be used either as a backup mode or a manual mode of operation.

3.1.4 Typical Minicontract Clearance

"Mike 127 is cleared to merge into arrival stream. You are number two behind Carson 447 with 3.2 km (2 nm) spacing. Maintain 750 meters (2500 feet) until established in trail position. Report in position before changing altitude".

(after reporting in trail)

"New York arrival has radar confirmation of your position in the stream. Descend and maintain 600 meters (2000 feet). Maintain 3.2 Km (2 nm) spacing on Carson 447".

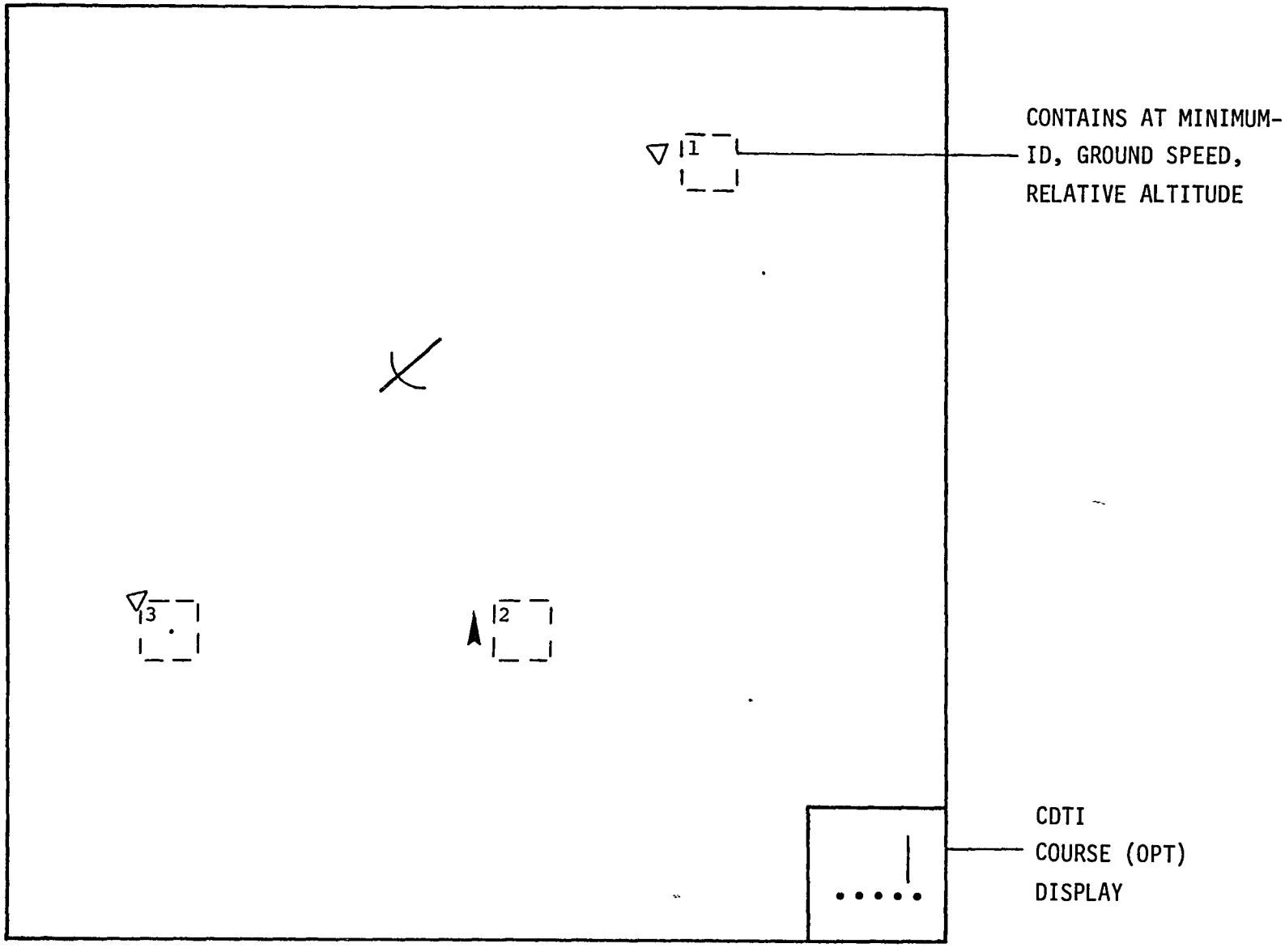

Figure 3.1 CDTI Merge Display

3.1.5 Operational Considerations

Because of the generally common flow of the merging procedure, displayed range need not be overly extensive. The pilot should have the capability of selecting several ranges through a single switch operation, particularly during the final phases of the merge operation. Additionally displays must undergo vertical filtering to avoid unnecessary distractions and display clutter. Approximate filter threshold levels should be established (relative to the subject aircraft altitude) with less differential required if a more complex filter is used. The display block described above will include all aircraft involved in the merge and still allow fine delineations of position and distance. All aircraft which enter this block should be displayed regardless of their involvement in the merging procedure. Additionally all aircraft which are involved, either directly or indirectly, in the merge must be notified of that fact before actual procedural initiation. This will be particularly pertinent in the future ATC system when DABS is introduced because of the discrete addressing capability it may have.

3.1.6 Comments

The CDTI merge is a basic tool which shows great promise of being incorporated into more complex procedures. Thus it must be developed and finalized early in the program so that it is available for use in more complex procedures as they are developed. Use in the near term system will require that the display and the information shown on it be the raw source of data for course and speed modification decisions performed either by on-board computers or the pilot. In the far term or future ATC system this displayed information is expected to function in more of a monitoring and/or operator assurance role.

3.2 SPACING

3.2.1 Potential Application

The spacing procedure is the second basic tool of CDTI operations, applicable to virtually all phases of flight. Procedurally it is a logical extension of the merge procedure and can be used as an independent procedure or can be adapted as an integral part of a more complex operation.

Although similar in nature to a merge, spacing involves a separate set of considerations to be investigated. Many of these considerations are based on two important factors in the spacing situation, namely lack of altitude separation and the attempt by the human operator to maintain strict spacing criteria. Properly designed, the spacing procedure will prove to be a valuable asset and a necessary adjunct to the CDTI flight environment.

3.2.2. Procedural Concept

The spacing process, like merging, is dependent on establishing and maintaining a specified clearance between aircraft in a stream. The most practical method of doing this is to have each aircraft maintain the desired spacing from the aircraft in front of him. This then becomes his point of navigational reference or target aircraft. Because of the dynamics involved in a merging operation, the target aircraft of necessity becomes the sole source of navigational reference. Spacing operations, because of their potentially long duration, must involve periodic monitoring of ground-reference navigation systems, but the primary reference system must continue to be the target aircraft. All clearances, delivered in terms of mini-contracts, should reflect this point of reference. Spacing contract clearances should not be issued until the aircraft is in position and established on speed. This position should be confirmed by both the controller and the pilot prior to issuance or acceptance of the spacing clearance.

3.2.3 Typical Spacing Clearance

"Mike 127 is cleared to maintain 3.2 km (2 nm) spacing behind Carson 447 until reaching the Brent intersection. Report any navigation deviations in excess of 4.8 kn (3 nm). I show you in position at this time."

3.2.4 Typical Spacing Procedure Cockpit Display

Perhaps the biggest deterrent to an efficient airborne directed stream spacing operation is pilot induced position over-correction and the consequent magnification of these movements throughout the length

of the stream. This phenomenon will be referred to as the "accordion effect". When interacting over a relatively long stream of aircraft, this effect can result in rather dramatic dynamic position movements even when initiated by small power or speed changes in the lead aircraft. The phenomenon magnifies throughout the stream primarily because the conscientious pilot who sees himself out of position will take positive and immediate steps to correct the situation. For this reason it is recommended that his display show, not a precise position he should ideally be occupying, but rather a range of acceptable positions or a position box. The dimensions of this box will of course depend on the spacing desired for the stream situation but should be large enough to permit an acceptable level of relative position wandering while not large enough to be a detriment to safety in a worst case situation. For 3.2 km (2 nm) spacing a .8 km (1/2 nm) wander increment should be the maximum acceptable. In a worst case situation this would still allow 2.4 kn (1 1/2 nm) separation, while providing approximately 1.6 km (1 nm) allowable deviation.

This concept is displayed in Figure 3.2 with a 3.2 ± .8 km (2± 1/2 nm) separation criteria in effect. Identification blocks contain the same information as the merging procedure with the groundspeed readout being paramount for the spacing operation. The position box is used to display the acceptable position locations for the subject aircraft and is generated by combining two parameters, cockpit selectable desired separation requirements and the historical track of the target aircraft. By defining position reference in terms of an acceptable limit rather than an idealized point, abrupt power corrections should be minimized thus tending to dampen out the accordion effect, rather than magnify it, as the correction works its way through the following aircraft stream.

The primary element of information needed to successfully perform the spacing procedure is subject aircraft speed relative to the target aircraft. Ideally this speed should be in terms of ground speed but comparable airspeeds are adequate providing the altitude differences and/or spacing distances are relatively small. For this reason the

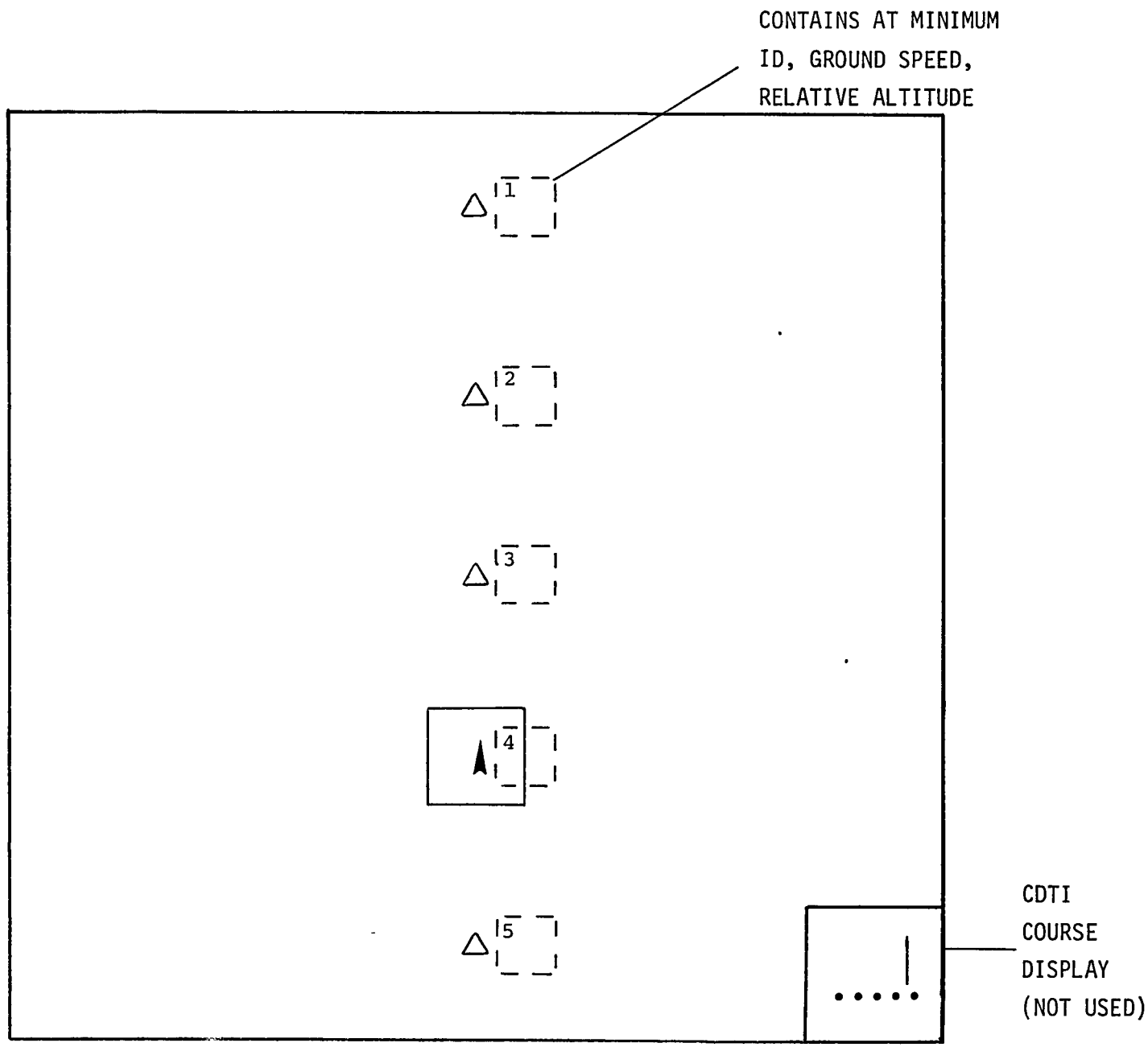

Figure 3.2 CDTI Spacing Display

optional CDI described in the section dealing with the merge procedure has little or no utility in this procedure. It is not recommended, however, that the same instrumentation be used as a speed deviation indicator, since this would tend to be confusing to the pilot. It is felt the digital readout contained in the identification blocks is an adequate indication of relative speeds for the successful performance of the spacing procedure.

3.2.5 Operational Considerations

All spacing maneuvers are dependent upon the relative speeds of the aircraft involved in the maneuver. This is true regardless of the means by which the maneuver is being accomplished. The desired position display as described above should eliminate the dynamic magnification tendency resulting in the accordion effect. It will not, however, effectively deal with a planned airspeed change associated with a specific geographic location. For example, as the lead aircraft in a stream reaches a planned speed reduction point and reduces his power, ideally each aircraft in that stream must simultaneously reduce his power in order to maintain his relative spacing position. The same phenomenon occurs in reverse at an acceleration point. In an enroute structure this discussion is, practically speaking, academic since the precise location of deceleration and acceleration points is relatively unimportant to individual aircraft. The accordion effect in the enroute is depicted in Figure 3.3 using a five aircraft stream maintaining 4.8 km (3 nm) spacing. TERMI is a programmed deceleration point which has no closure of spacing associated with it. Assuming perfect maintenance of spacing, as aircraft A decelerates at TERMI, all other aircraft in the stream must simultaneously decelerate to maintain proper spacing. Thus the deceleration point for aircraft 5 is 19.2 km (12 nm) prior to TERMI.

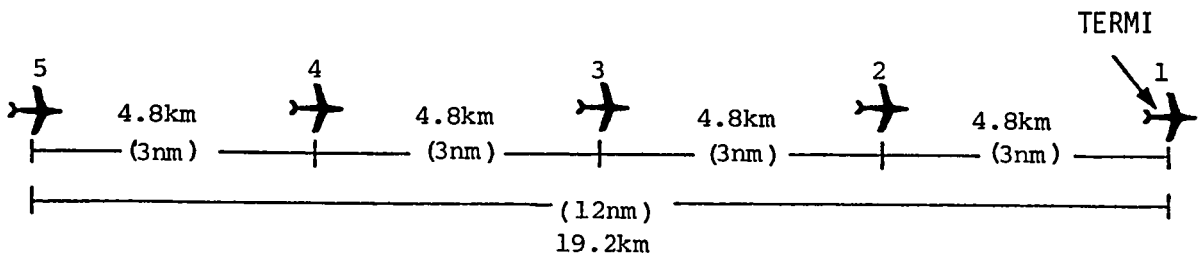

Figure 3.3 Accordion Effect Enroute

In a terminal area situation, this phenomenon becomes of significant importance since the dynamic movement of acceleration and deceleration points has the potential for significantly altering the configuration sequence for individual aircraft in a long stream. From a cockpit workload perspective, this is an unacceptable situation. It is recommended therefore that approach procedures utilizing this, or a similar spacing maneuver, be designed so that programmed deceleration points be geographically coincident with the initial points of reduced separation legs. Thus, as the target aircraft (as described above) reaches a programmed deceleration point (e.g., the final approach fix) and reduces speed, the primary aircraft will be able to maintain speed until reaching the same geographical point or fix, thus reducing the spacing. This is depicted in Figure 3.4 where reduced spacing is maintained after passing deceleration point ANNAN. The precise amount of allowable airspeed reduction and reduced spacing are interdependent variables and will depend upon aircraft performance and airport capacity requirements. This same sequence would apply in reverse at acceleration fixes. This maneuver will be adopted for all approach and landing procedures developed and dicussed in this report.

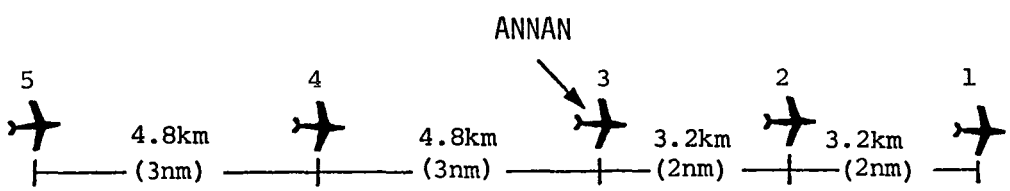

Figure 3.4 Accordion Effect Terminal Area Modification

3.2.6 Comments

CDTI spacing is an important aspect of many potential CDTI procedures. As with the merging procedure, it should be developed and finalized early in the program so that it is validated and available during the further development of the more complex procedures. Alleviation of the two inherent drawbacks to all spacing maneuvers, the

accordion effect and undesirable stream expansion and contraction, is necessary prior to the successful implementation of the more complex CDTI procedures planned for terminal area traffic control in the future. The procedure outlined above should be instrumental in eliminating these problems.

3.3 PARALLEL APPROACHES TO CLOSELY SPACED PARALLEL RUNWAYS

3.3.1 Potential Application

Increased air traffic demands are most visibly reflected in terminal area operations serving major hub airports. Many of these airports are currently operating at full capacity during peak demand operating hours. Surprisingly, the limiting capacity factor in most terminal areas is not the lack of available airspace but the availability of runway utilization time. Runway availability is influenced by a variety of local conditions such as runway occupancy time and wake vortex formation and dispersion, but the most direct solution to the problem has traditionally been to build additional non-intersecting runways. Safety considerations require that these parallel runways be adequately separated in order to assure that their respective traffic patterns do not interfere with each other. This is relatively non-restrictive during periods of good visibility when one or both of the runways can be operated under visual flight rules (VFR). Runway separation standards must become much more restrictive during periods of IFR operation however.

Increased runway separation requirements for simultaneous IFR operations create a problem for most major hub airports because of the limited amount of available real estate at the airport site. In many cases it is physically impossible to construct parallel runways under the current separation standards using the land available to airport management. Acquisition of additional land is often prohibitively expensive. On the other hand a means of safely reducing the standard for IFR operations would enable many airports to construct additional runways, thus significantly increasing their

potential capacity. The CDTI concept and the development of safe approach procedures utilizing it has the potential to produce the environment needed to safely reduce these runway separation standards.

Perhaps the most basic approach structure which can be visualized utilizing reduced separation runways is the parallel approach path situation. This structure, in reality, is simply an extension of typical VFR operations into the IFR regime. Although minor adaptations must be made in the interest of safety, IFR procedures should be based as closely as possible on those VFR procedures which have been proven through operational experience.

3.3.2 Procedural Concept

Simultaneous IFR approaches to dual parallel runways is a procedure which is currently being routinely accomplished at several major airports across the country. Minimum separation standards for these approaches are typically 1350-1500 meters (4500-5000 feet). Lateral separation standards of 750 meters (2500 feet) would enable parallel runway operation under IFR conditions at more major airport hub locations. This means that, under capacity loading, a buffer of only 750 meters (2500 feet) is established between streams of arriving aircraft. This separation is inadequate for routine operations involving aircraft at the same altitude in an IMC environment. Thus any approach procedure must identify means of obtaining additional aircraft spacing to be considered operationally feasible.

Current spacing practice for sequentially landing traffic on a single runway indicates that a minimum of 4.8 km (3 nm) longitudinal spacing between aircraft on final approach is needed for safe terminal area airspace utilization. The driving factors upon which this figure appears to be based are runway occupancy time and the dynamics of wake vortex formation. Although these factors are currently under intensive study, and solutions may be forthcoming in the near future, it should be assumed that the 4.8 km (3 nm) limitation may be a regulatory constraint for some time to come.

This spacing constraint can be put to practical use in the parallel approach path case, however. If both streams are composed of aircraft with compatible final approach speeds, aircraft longitudual spacing can be adjusted such that the streams are longitudinally staggered. This situation is illustrated in Figure 3.5. As an example, assume that the subject aircraft is in a stream approaching runway 18R with 4.8 km (3 nm) spacing. The stream approaching 18L also has 4.8 km (3 nm) spacing with final approach speeds compatible with the subject aircraft stream. Lateral separation between streams is approximately .8 km (1/2 nm). By synchronizing the two streams such that each aircraft occupies a position abeam a space in the adjacent stream, actual aircraft to aircraft separation will be 2.6 km (1 1/2 nm). Hopefully this will be an acceptable separation standard for a controlled environment.

Although the above described procedure offers a possible solution to the problem of maintaining adequate aircraft separation, there are functional disadvantages inherent in its practical utilization. Perhaps the most important of these is the interdependent relationship which exists between the two streams. Development of a procedure which enables independent operation of two adjacent streams would be conducive to a functionally more versatile system. As an example, an independent procedure would not require interstream compatibility of final approach airspeeds. One method of obtaining stream independence while maintaining safe aircraft separation standards is by introducing altitude separation. Altitude separation is commonly used in many phases of flight as a means of primary aircraft separation. This same principle can be applied to the final approach phase of flight as well. Initial glide slope interception generally signifies the beginning of the final approach portion of a precision approach. Precision glide slopes currently vary from two to five degrees depending upon the facility with most programmed to be three degrees. One degree of change

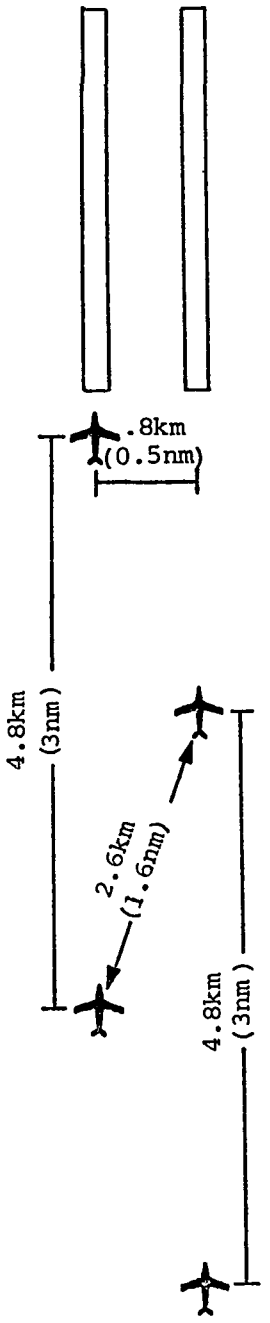

Figure 3.5 Dependently Controlled Parallel Approaches

in glide slope equates to 30 meters (100 feet) of altitude variation for each 1.6 km (mile) away from the transmitter. Thus at 4.8 km (3 nm) from touchdown one degree of glide slope difference would equate to 90 meters (300 feet) of altitude difference. This difference could be further increased by longitudinally offsetting the parallel runways.

Based upon this concept, it is recommended that closely spaced parallel approaches be designed as depicted in Figure 3.6. Each final approach segment is fed by its own base leg from a standard rectangular pattern. It should be noted that the respective final approach course interceptions occur at different distances from the touchdown point in order to alleviate any potential problems due to final approach course overshoot. Altitude separation during this phase of the approach is 210 meters (700 feet). Glide slope interception for both streams occurs 11.2 km (7 nm) from touchdown. As depicted, the aircraft on the left (at a lower altitude) uses a 2 1/2° glide slope while the aircraft on the right (at a higher altitude) uses a 3 1/2° glide slope. Precise glide slope angles are relatively unimportant during initial concept development, but the difference between the glide slope values ultimately determines the amount of altitude separation planned at any particular point during the final approach segment.

The introduction of the concept of altitude separation during the final approach phase of flight makes approach path independence feasible. Thus, it becomes possible to assign aircraft to specific approach paths based upon their expected final approach speed. The resulting configuration would enable the formation of a high speed lane and a low speed lane. Alternatively, in the face of the consideration of the impact of wake vortices concern, approach path assignment could be based upon aircraft gross weight. Regardless of the basis of path assignment, approach path independence made possible by the introduction of altitude separation will potentially provide some measure of the flexibility needed in terminal area procedures as capacity demands increase.

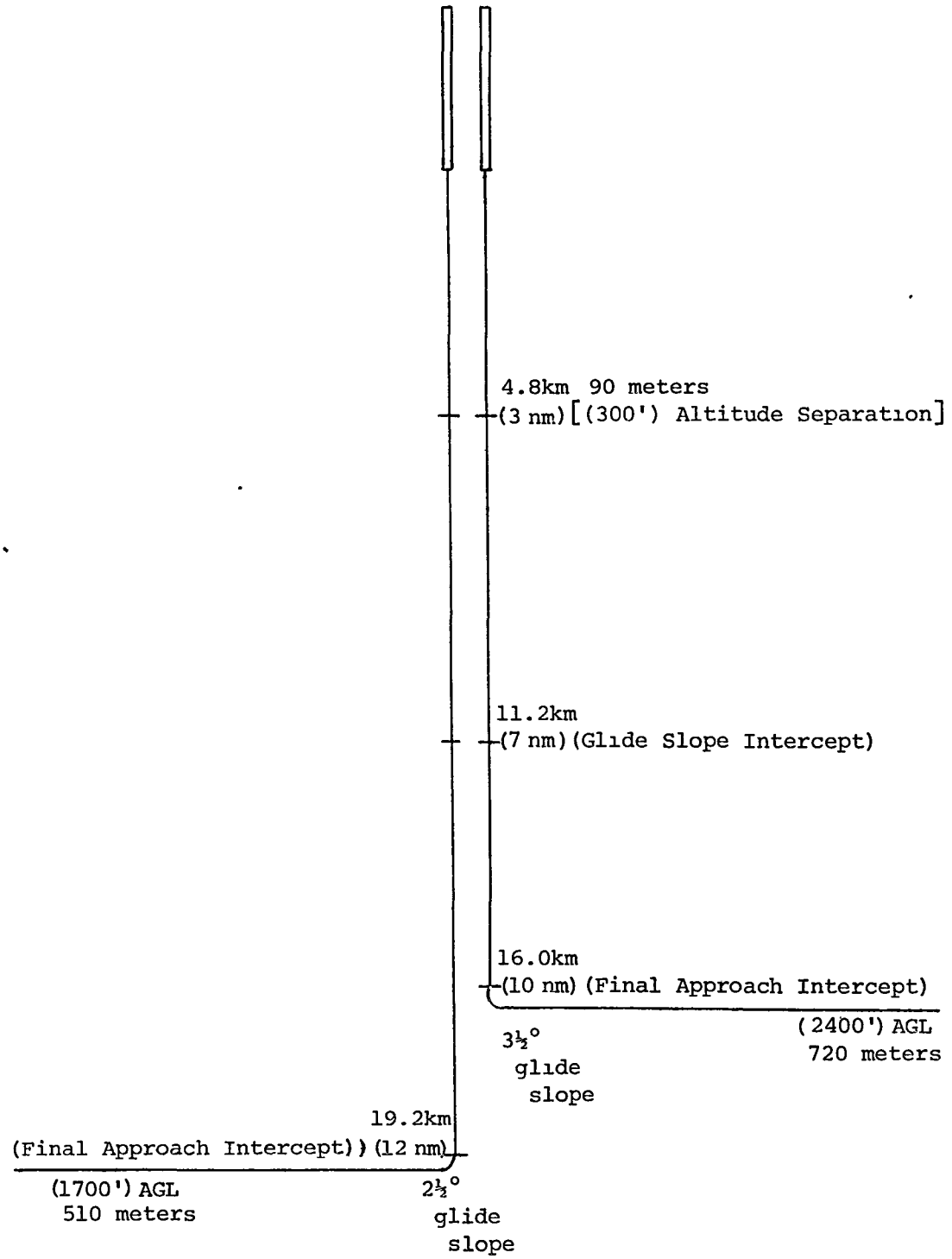

Figure 3.6 Independently Controlled Parallel Approaches

3.3.3 Typical Display

The primary CDTI display for this procedure is the typical spacing display described in Section 3.2. Because of the close lateral proximity of traffic, it is recommended that the position box be of smaller dimensions than that previously generically described. This can easily be accomplished by including in the equipment design an approach mode switch which keys the display system software pertinent to the flight regime being transitioned. Operation of this switch can be either manual or automatic (via data link or activated by gear extension, etc.). Associated with this switch should be an indicator light for ease of identification of activation status of the switch. Although some method of displaying minimum acceptable lateral separation standards would be beneficial it is felt that they would tend to clutter the display and possibly significantly increase cockpit workload. Since the position box concept can present most of the same information, it recommended that minimum lateral separation standards not be included in the display at this time.

3.3.4 Typical Clearance

"Mike 127 is cleared for the ILS-2 approach to Runway 09R. Maintain 4.8 km (3 nm) spacing on Carson 447. Call final approach fix inbound for final landing clearance".

(After reporting final approach fix)

"Mike 127 is cleared to land Runway 09R. You are number three behind Carson 447. Overtaking traffic on final approach to 09L. Report in sight by visual or electronic means".

3.3.5 Operational Considerations

The required positional accuracy necessary for safe implementation of the parallel approach path procedure should be technologically available in the future ATC system. Implementation of this procedure in the near term system, although conceivable, should be regarded as improbable. It is doubtful that the ILS signals in common use today are capable of providing the required navigational accuracies consistently. Additionally, navigation transmitters located in close geographic

proximity to each other may display unexpected characteristics of mutual frequency interference, thus further degrading accuracy and reliability. A parallel approach path concept implemented using ILS navigation signals could be affected by this interference. An MLS/RNAV system, on the other hand, will be capable of providing guidance to each of two parallel approach paths from a single signal source.

A second practical consideration is the effect of having longitudinally offset parallel runways. With one degree of difference between the parallel course glide slopes, altitude separation increases at the rate of 30 meters (100 feet) per 1.6 km (1 nm) from touchdown. By longitudinally separating the runway thresholds by only 1.6 km (1 nm), (with the 3 1/2° glide slope runway threshold 1.6 km (1 nm) further on final than the 2 1/2° glide slope runway threshold) vertical separation is increased by approximately 105 meters (350 feet) throughout all segments of the approach. This is a significant increase and could possibly be the practical difference between a safe operational procedure and an unsafe one.

3.3.6 Comments

Regardless of the electronic aids available to the overall system, acceptance of VMC spacing standards in an IMC environment will be difficult to gain. FAA regulatory agencies will have to be shown that all procedures developed are, in reality, as safe as those procedures in current practice. This, of course, is a totally reasonable requirement which should be applied to any new procedural concept. In addition to FAA acceptance, reduced spacing standards must also be accepted by the users, pilots and controllers. This may well be the most difficult task to accomplish. Traditional training has instilled in experienced pilots the need for maintaining positive aircraft separation in IFR conditions. Since it is important that user groups feel comfortable with any given procedure, separation standards generally incorporate additional airspace above and beyond that indicated by error budget analyses. This additional airspace serves as a comfort factor to pilots operating in a regime in which they are dependent on other

individuals to maintain aircraft separation. A reliable CDTI display will enable a pilot to, at a minimum, monitor his own separation. This should be a major influence in establishing pilot acceptance of reduced separation standards.

3.4 DUAL APPROACH PATHS TO A SINGLE RUNWAY

3.4.1 Introduction and Comments

The concept of establishing dual approach paths to a single runway has been considered as one possible means of increasing terminal area capacity in an IMC environment. Several factors contribute to making this an impractical concept. Peak capacity separation standards are currently based upon two constraints neither of which would be alleviated by a dual approach path concept. These constraints are runway occupancy time and wake vortex dispersion. Although variances from one airport to another are to be expected, average occupancy times are generally in the neighborhood of 50-55 seconds, while the effect of wake vortices can be influential for up to two minutes if the conditions are right. A dual approach path procedure to a single runway would necessarily include a merge at some point on a common final approach path prior to touchdown, thus negating any capacity benefits which could be gained by the procedure during the approach phase.

The near term environment, as defined in this study, assumes that runway occupancy time and wake vortex considerations will be reduced, however. Even in this improved environment there are some considerations which make a dual approach procedure impractical. Primary among these considerations is the merging segment under peak traffic conditions. Under the best of conditions a merge is a relatively complex procedure and preferably one which should not be planned during a final approach segment unless specific benefits can be assured. With the implementation of MLS and its multiple glide slope capability, the dual approach concept becomes feasible as a special case of the multiple curved approach procedure and will be discussed in that section of this report. The inability of ILS

to provide guidance for more than one final approach course is another factor which must be considered in the near term environment. If it is assumed that ILS guidance is provided for one of the two approach courses under consideration, the question arises of what type of guidance would be provided for the other approach course. A dual ILS facility would be expensive and might be subject to frequency interference problems. Any other type of guidance would be of a non-precision nature and not conducive to aircraft operations in close proximity to each other.

The benefits to be derived from a dual approach concept are limited in scope. It is doubtful that additional capacity benefits can be derived since both segments of a dual approach procedure must ultimately merge into a single stream. The spacing on this single stream segment would be the limiting factor for total capacity capability. Limited benefits could be realized in the case of aircraft maintaining different final approach airspeeds, but these benefits would not prove to be significant. As an example, with 4.8 km (3 nm) separation and a 60 knot difference in final approach speeds (60 KIAS and 120 KIAS), a complete pass would require approximately 19.2 km (12 nm). This is a large distance during the final approach phase and the situation could be more readily operationally controlled through timing adjustments based on base leg positioning.

For these reasons, no actual procedure will be developed and analyzed in this study for the case of a dual approach path to a single runway CDTI role in the near term ATC environment. For the far term or future environment this procedure will be considered a special case of the multiple curved approach procedure, and will be further discussed in the next section.

3.5 MULTIPLE CURVED APPROACH PATHS

3.5.1 Potential Application

Perhaps the biggest challenge facing the ATC system of the future is the integration of aircraft of wide ranging performance capabilities into enroute and terminal area structures. It is expected that computerization and advanced metering and spacing techniques will be the basis for this integration in a manner which minimizes delays and inconvenience

to the user aircraft. The enroute structure can better accommodate large traffic load factors because of the relatively large range of vertical levels which can be used for traffic separation. Today, these levels are used primarily for separation of opposite direction traffic. In the future, it is expected that upgraded computerization will enable efficient vertical separation of same direction traffic operating under different performance capabilities.

Integration of aircraft in the terminal areas is a more difficult problem, however. All aircraft intending to land on a particular runway must transit the same general airspace, depending primarily on timing to maintain spacing and separation. Computerized metering and spacing techniques should be capable of determining aircraft sequencing and spacing requirements, but procedures must be developed to account for the difference in performance capabilities of interacting aircraft. One method of procedurally accomplishing this is to develop a terminal area structure defining several approach paths, each tied to a specified final approach speed, which terminate at a common point just short of a designated runway. A number of technological developments will necessarily have to be implemented before this type of terminal area structure can be constructed. These include advanced recomputerization, MLS final approach guidance (tied to area navigation), computerized metering and spacing, advanced flight management computerization, and improved final approach monitoring capability. For this reason feasible implementation of this type of terminal structure is limited to the future ATC environment as defined by this study.

Multiple curved path approaches can be implemented in a variety of runway environments, but benefits will most readily accrue from implementation in a single runway or dual parallel runway environment. These are the environments for which the structure was planned and will be the only environment discussed in this report. It should be recognized, however, that with minimum modifications the structure can be designed to fit a number of other runway environments. For example, non-parallel runways could be accommodated by rotating that portion of the structure

which normally relates to one of two parallel runways such that the structure is aligned with two nonparallel runways. Modification of missed approach procedures would have to be accomplished with emphasis placed on local physical environment characteristics. Intersecting runways would create additional constraints, but could be accommodated with appropriate metering and spacing techniques. Independent of the specific airport design, this procedure could be modified to accommodate unique local restrictions, but maximum benefit will be accrued in a parallel runway environment.

3.5.2 Procedural Concept

A terminal area configured with multiple curved approach paths can be a complex structure. Each new approach path dynamically adds to the potential aircraft interactions present in the system. For this reason it is recommended that all structures be maintained at the most basic level compatible with capacity demands and aircraft mix. For the purposes of this study, a structure consisting of six paths approaching a pair of parallel runways will be developed and analyzed. This is the most complex structure which should be considered practical for approaches to a runway complex.

The terminal area structure is the most important aspect of this procedure. It consists of a carefully planned set of established merge points designed to laterally separate aircraft on final approach based upon performance capability criteria. Because of potential airspeed and performance incompatibilities, the integration of aircraft with differing performance capabilities is planned to culminate in the shortest possible common routing consistent with safe aircraft operational constraints. Where merging points are required, altitude separation is afforded. A plan view depiction of the proposed structure is presented in Figure 3.7. For ease of discussion the prospective approach paths are identified by alpha characters, with A, B, and C approaching the left runway and D, E, and F approaching the right runway. Alpha character identification is also recommended for path assignment in an operational situation. Planned merge points are established at 6.4 kn (4 nm) (A) and 12.8 km (8 nm) (B) for the left runway and at 3.2 km (2 nm) (F) and

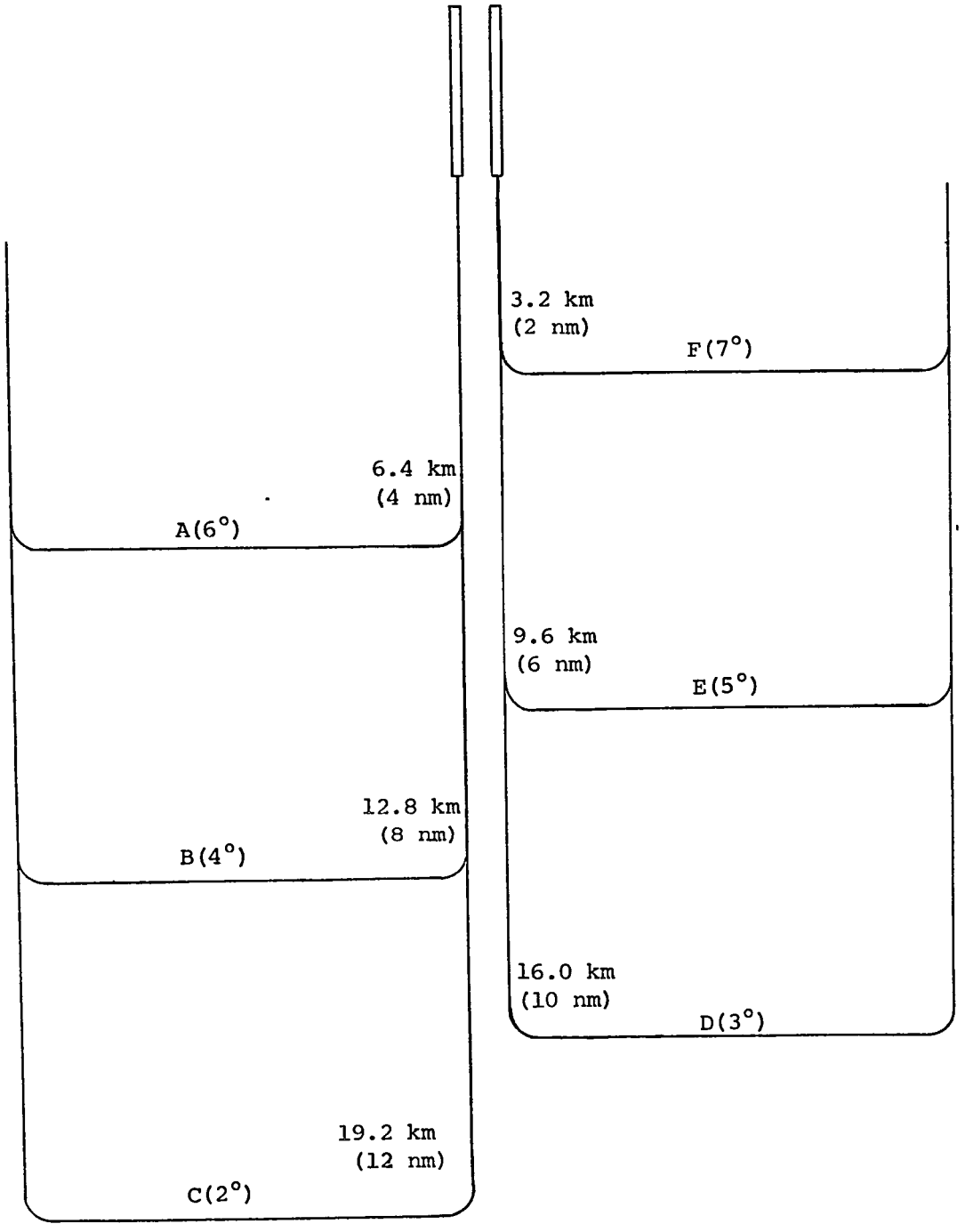

Figure 3.7 Multiple Curved Approach Path Structure

9.6 kn (6 nm) (E) for the right. Each of the approach paths are integrally associated with specific glide slope assignments and final approach speed performance capabilities. Glide slope assignments are nominally set at the following value:

A - 6.0°	D - 3.0°
B - 4.0°	E - 5.0°
C - 2.0°	F - 7.0°

This affords a minimum of 120 meter (400 feet) altitude separation at any merge point. Altitude separation figures are estimates based upon the premise that elevation increases approximately 30 meter (100 feet) for each degree of glide slope angle for every 1.6 kn (1 nm) from the glide slope transmitter (100 ft/°/nm). This approach approximation is valid in the regime of the small angles associated with glide slopes.

As was dicussed earlier in this section, approach path assignment should be based on individual aircraft approach performance criteria. Although definitive final approach speed values cannot be definitively assigned at this time, faster aircraft should be assigned those paths with longer straight-in final approach segments. This is based upon the fact that the faster aircraft will generally tend to be larger and less maneuverable. Airspeed values for each path will depend upon the aircraft mix at the specific airport involved and may be influenced by the specific situational requirements.

In order to further maintain vertical separation between aircraft within the terminal area, each approach path should have a specific initial pattern altitude associated with it. The following pattern altitudes are recommended for the structure depicted in Figure 3.7:

Approach Path	Pattern Altitude	Glide Slope Intercept
A	1050 m (3500')AGL	10.0 km (5.5) nm
B	750 m (2500')AGL	10.7 km (5.9) nm
C	450 m (1500')AGL	12.9 km (7.1) nm
D	600 m (2000')AGL	11.4 km (6.3) nm
E	900 m (3000')AGL	10.3 km (5.6) nm
F	1200 m (4000')AGL	9.8 km (5.4) nm

These values will ensure 300 meter (1000 foot) separation between aircraft in the same pattern, thus reducing potential conflicts between aircraft with different performance characteristics during the initial stages of the terminal area phase of flight. Glide slope interception should occur in approximately the same relative location for a aircraft on each of the approach paths. This interception would occur at points of minimal workload for all approach path cases except in the case of approach path E where glide slope intercept would occur at the merge point. Further testing will be required to determine the overall effect of this possible workload conflict on error budget requirements and blunder potential, but altitude differentials of a minimum of 180 meters (600 feet) should preclude any serious conflicts with nearby aircraft.

The complexity and dynamic nature of this structure requires that it be very stringently controlled. Timing is of the utmost importance, particularly during periods of peak activity. Aircraft sequencing and spacing requirements should be established as early as possible to simplify entry into and operations within the terminal control area. Ideally, timing should be established by highly sophisticated metering and spacing techniques integrated with advanced ATC recomputerization hardware and software. Without access to the information supplied by these metering and spacing systems, practical operation of a structure of this complexity would be impossible. As with any highly interactive system, predictability of the component parts is of primary importance to the stability of the whole system. This translates to the need for discipline and strict adherance to timing and spacing requirements by every aircraft integrated into this system.

The terminal area structure described above is designed to meet an extremely demanding traffic environment. In practice, there will be few environments which are, in fact, this demanding. This procedure should be simplified through modification in order to meet traffic demands by the most direct means. In localities where peak traffic demands allow it, the terminal structure should be designed to contain only two approach paths per runway. At those airports not serviced by

dual parallel runways, one rectangular pattern with its associated final approach paths should be used. Pattern modifications will depend upon the characteristics of the terminal area being serviced, but the basic procedural principles are presented here.

3.5.3 Typical CDTI Display

The cockpit displays required for the multiple curved approach path procedure are those described for the merging (Fig. 3.1) and the spacing (Fig. 3.2) procedures with one minor modification. The position box for the spacing display should be reduced in size to accommodate the tight spacing requirements of the terminal area flight regime. This can be accomplished through an approach mode switch as described in the discussion on parallel approaches to closely spaced parallel runways. Activation of this switch can be manual or automatic, through data link signal coding. Appropriate indicator lighting or annunciation should be included in the appraoch mode switch modification.

3.5.4 Typical Approach and Landing Clearance

This procedure does not lend itself to typical clearances as most of the other procedures do as each situation is unique, depending on programmed sequencing, current spacing, and performance parameters of interacting aircraft. Many of these factors will have to be included in the approach clearance. This can best be illustrated by presenting a situational example. Mike 127 is to use the A approach path and land 3.2 km (2 nm) behind Carson 447. Packer 431 is also going to be using the A approach path and will be landing 3.2 km (2 nm) ahead of Carson 447. For this situation the following clearance might be given.

"Mike 127 descend and maintain 1050 meters (3500'). You are cleared for the MLS - Alpha approach to Runway 09 Left at Riverdale Airport. Maintain 6.4 km (4 nm) spacing on Packer 431 until merging into final approach course stream. On final approach maintain 3.2 km (2 NM) spacing on Carson 447. You are number three to land on 09 left."

3.5.5 Operational Considerations

The complexity of this procedure makes it imperative that several operational factors be further considered and their effects be operationally

evaluated prior to implementation. The testing and evaluation will not, however, pose a significant time constraint, as implementation of even a basic version of this procedure will not occur until after the accomplishment of several important technological advances.

The first consideration is the formulation of generalized right-of-way rules. Although metering and spacing techniques will minimize potential conflicts, planned "escape" routes must be available for those occasions when conflicts do arise. A six path structure creates planning difficulties when considering all possible contingencies. In general, however, aircraft established on the straight-in segment when parallel approach operations are being simultaneously conducted must be given the right-of-way in all potential conflict situations. This is necessary because from this position a climbing turn out of traffic may put them in conflict with traffic on other approach paths. Single runway operations will not require this to be the case, as an aircraft on the straight-in segment can execute a missed approach turn in the direction away from the active traffic pattern.

The situation which is currently unresolved is the one where there is traffic on paths A, B, and C, (or D, E, and F) with a potential conflict between B and C (D and E). In this situation, the altitude separation inherently available in this plan will have to be depended upon until adequate lateral clearance can be obtained to initiate the missed approach. Altitude separation between all aircraft should be a minimum of 300 meters (1000 feet) using the structure and altitudes described in this report. The presence of an on-board CDTI display should make this worst case situation more palatable to all parties involved. In any case, the resolution of all potential conflicts should be determined by the final merge point in either pattern, at which time altitude separation will still be approximately 150 meters (500 feet). Missed approach considerations will be further explained in Section 3.7 of this report.

Altitude separation for this structure is established through the use of different final approach glide slopes. In order to maintain

adequate altitude separation at critical points in the planned approach it was necessary to incorporate a 7.0° glide slope in the planned procedure structure. Glide path intercept is expected approximately 9.8 km (5.4 nm) from the runway. Because of the signal geometry, initial descent rates will be somewhat less than those required to maintain a 7.0 degree glide slope and the aircraft will have approximately 12.8 km (8 nm) to fly after initial intercept. MLS glide slope indications are computed on a straight line basis from the transmitter to the aircraft. Approach path F will encounter intercept at some point during the base leg segment. Initially, since the direction of flight is not directly toward the transmitter, the actual descent rates will be significantly reduced. Only after turning onto the straight-in segment of the approach will true 7° glide slope descent rates be required. The workload impact of this phenomenon will have to be tested to determine the feasibility of this type of approach path before system implementation.

Another closely associated cockpit workload consideration is the impact of the situation when glide slope intercept is concurrent with final approach course intercept. This occurs on the E approach path depicted in Figure 3.7. With a 5° glide slope and an initial altitude of 900 meters (3000 feet) AGL, glide slope intercept will occur approximately at the 9.6 km (6 nm) point. This is the planned merge point for this approach path. Although the merging operation should be essentially complete prior to the start descent point, extensive testing should be conducted to determine the workload implications of this dual action point. Modifications should be made to the overall route structure if it is proven to be detrimental to safety.

3.5.6 Comments

This procedure was designed as a possible far term solution to a potential capacity demand problem. Many of the required technological advances required are still being developed. Implementation of these advances in the ATC system will technically enable this procedure to be performed but the availability of an on-board CDTI display will be the determining factor in pilot and controller acceptance. Operationally,

this procedure will have to be thoroughly tested and gradually implemented. The procedure outlined in this section should be considered only as a final fully implemented procedure and not as an intermediate terminal area structure capable of immediate implementation.

3.6 COCKPIT MONITORING OF RUNWAY ENVIRONMENT

3.6.1 Potential Application

Final approach spacing is dependent on a number of factors not directly related to positive aircraft separation. In today's ATC environment two of these, runway occupancy time and wake vortex avoidance, constitute the limiting factors in maximizing capacity capabilities. Although this study assumes that methods of reducing the effect of these constraints will be developed in the near term future, they will continue to be an important consideration in the determination of final approach spacing requirements.

Runway occupancy time is a function of a variety of factors, many of which are qualitative in nature and not totally predictable from one incident to another. Estimates can be made, however, based on the configuration of available exiting taxiways commensurate with planned aircraft stopping distances. Historical data can be collected and used for confirmation of predicted runway occupancy time means and standard deviations. The element of pilot judgement, however, increases variability thus reducing specific predictability. Motivation is perhaps the most influential variable. Gate assignments and their location relative to the landing runway can have a significant influence on the amount of time a particular aircraft occupies an active runway. The point of actual touchdown and the associated landing techniques can also influence occupancy time. Aircraft performance criteria, although quantitative in nature, can add variability in a mixed aircraft stream. Requirements designed to assure that two aircraft are not conducting operations on the same runway at the same time dictate the spacing needed on final approach. In order to minimize the number of missed approaches, worst case situations must be considered as the driving force for standardizing final approach spacing.

In a visual environment, the pilot of an aircraft on short final can evaluate the overall runway situation and thus is willing to accept reduced spacing from the preceding aircraft. In conditions of reduced visibility, it is well within the realm of possibility that the departure end of the runway is not visible from the approach end, even though the weather is well above landing minimums. In conditions such as this, final approach spacing must be increased to assure compliance with occupancy requirements. This results in an overall decreased in capacity capability during IFR operations.

CDTI instrumentation affords the opportunity to alleviate this situation by providing the pilot with the information he needs to evaluate the runway environment. During single runway operations, when aircraft are both arriving and departing from the same runway, the need for this cockpit displayed information is increased significantly. The ability to visually monitor the runway environment in IFR conditions should reduce final approach spacing requirements without increasing missed approach potential. This, in conjunction with the incorporation of pilot motivational factors, should reduce runway occupancy time and thereby aid in increasing airport capacity capability.

3.6.2 Procedural Concept

Although limited in scope, the concept of runway environment monitoring is important to user acceptance of reduced approach spacing. This concept is not associated with a particular procedure, but instead, adds credibility to all those procedures which enable reduction in final approach spacing. Although particularly applicable during the last 3.2 - 4.8 km (2-3 nm) of the final approach phase, this concept can be used to periodically monitor the airport ground situation throughout the final approach phase. The runway environment display should be a separate mode selectable from the cockpit. Reference to this display throughout final approach can be made but should be of relatively short duration, particularly during those approaches requiring CDTI derived spacing. Once the target aircraft has entered the airport environment and is no longer an inflight consideration, this mode may be selected

and monitored throughout the landing phase. Although landing clearances could conceivably be based on the information presented by the runway monitor mode, this is not recommended as a standard procedure because of the additional "head-down" time it would entail during an extremely critical phase of flight. Initially, this concept should be limited to a monitor role for the primary purpose of promoting pilot assurance during landing operations.

3.6.3 Typical Runway Environment Display

Ideally the runway environment display mode should be considerably different than the other CDTI displays. Not only are the information requirements definitively different, but the display diversity will also serve as a positive indication of what display is being monitored in a high workload environment. Display of the runway environment should include a fixed plan view of the airport of interest overlaid with graphic representation of any pertinent traffic. Airborne traffic should be graphically differentiated from runway ground traffic in order to monitor current runway status. Although aircraft movement on other than active runways need not be depicted, all active runway operations should be displayed, including those taxi operations which cross operational runways. If taxi operations are displayed, graphic differentiation should be made between runway and taxiway operations.

An example of a typical runway monitor display is presented in Figure 3.8 where all aircraft movement which does not take place on the parking ramp is depicted. Airborne operations are represented by a triangle, runway operations by an X, and taxiway operations by a circle. Basic data, including the map underlay, is generated on the ground and is relayed through data link signal for interpretation and presentation in the aircraft. Key transition events, such as aircraft touchdown and crossing the hold line, should be used to establish the operational status of all displayed aircraft. Airborne aircraft representation should include a data block indicating identification, airspeed and altitude (AGL if feasible). Runway data blocks should indicate indentification only, while taxi operation

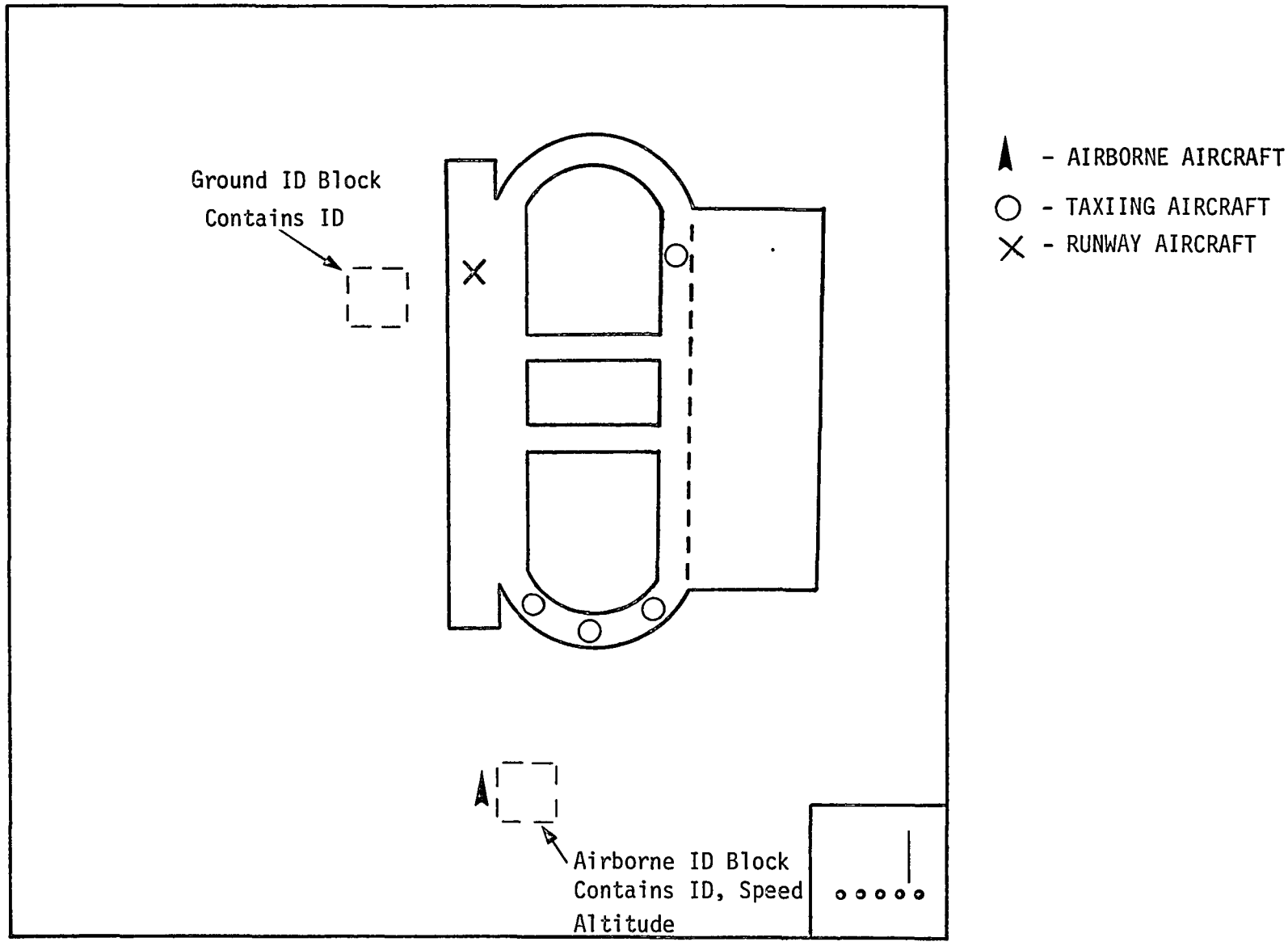

Figure 3.8 Ground Monitor Display

representations should not include any data block information (in order to avoid cluttering the display). This type of display will enable the pilot to interpret the overall runway environment with a quick glance and still supply him with any additional information he may desire for situational evaluation.

3.6.4 Typical Clearance

This procedural concept is designed for monitoring functions only and thus there is no control function clearance associated with it.

3.6.5 Operational Considerations

The primary operational factor to be considered in the implementation of the runway environment mode described in this section is its potential for providing undesirable distractions. Except when the aircraft is in the immediate vicinity of the airport, selection of this mode disables the primary function of CDTI equipment, portrayal of the traffic flow in the vicinity of the subject aircraft. Additionally, if a merging or spacing maneuver is being accomplished at the time of selection, basic procedural data flow, which is unattainable by the pilot through any other medium, is interrupted. Judicious use of the runway environment mode of operation will alleviate this problem, however. In the final analysis, the advantages during the landing phase outweigh any potential disadvantages due to pilot error in judgement.

It is highly recommended that all runway operations be displayed in this monitor role, not just the runway assigned for landing. This will prevent inadvertent landing on a nonassigned runway which is being used by nondisplayed traffic. Additionally, it may be possible to develop means of indicating those runways and/or taxiways which are closed for construction or otherwise nonoperational. Whenever providing this information, however, care must be taken to avoid unnecessarily cluttering the display. It is also recommended, in the interest of avoiding clutter, that some type of altitude filter, either ground or receiver based, be incorporated to avoid the unwanted

display of high altitude flyover traffic. In general, this mode should be used to display all of the aspects of the runway environment which relate to safe operations while avoiding the cluttering influence of displayed trivial aspects.

3.6.6 Comments

The ground monitoring display, while not essential for CDTI based operations, can be a positive influence in the ultimate problem of pilot and controller concept acceptance. The major disadvantage to this display is the possible distractive capability it may have during complex terminal area operations. The practical implication of these distractions must be examined through further operational testing and evaluation but, providing those implications are not excessive, the potential advantages in promoting pilot acceptance of reduced spacing operations and CDTI instrumentation in general, make development of this concept well worth the additional research cost it might entail.

3.7 MISSED APPROACHES

3.7.1 Potential Application

In a properly configured terminal area system a missed approach should be an unusual occurrance. Not only do missed approaches constitute an inconvenience to pilots and passengers, but they can also cause major disruptions to the overall traffic flow at facilities operating at or near peak capacity. Thorough planning can reduce potential traffic conflicts, while system flexibility can minimize the impact of those conflicts which do occur. In spite of this, deteriorating weather conditions can make it impossible to safely land out of an otherwise good approach and aircraft emergencies can dictate the requirement for making major revisions in planned landing sequences, resulting in the initiation of missed approach procedures unexpectedly. Thus, missed approach planning is an integral step in the development and design of operational terminal area procedures.

Often times the local environment dictates the nature of a missed approach procedure. Factors such as terrain clearance, local towers, noise abatement requirements, and proximity to other airports determine

The emphasis then, in this section, will be on the extrication phase of the missed approach procedure. There are two essential ingredients involved in this phase, a destination location from which reintegration can be safely initiated and a conflict free route from the current position to that destination. Although a delay will not necessarily be incurred at the destination location, for convenience this location will be termed the missed approach holding fix or, simply, the holding fix. Likewise the conflict free routing will be termed the delay routing. This terminology is not totally compatible with that in current usage today, but it will avoid confusion in the following discussions.

Ideally the holding fix should be located convenient to, but laterally and vertically clear of, both arrival and departure traffic streams. In the case of simultaneous approaches to parallel runway complexes each runway should have its own holding fix. Delay routings should be conflict free of all approach and departure routings with positive altitude separation at all crossing points. User aircraft climb performance capability should be a major planning concern to avoid altitude design structure restrictions which cannot be met by all terminal users. Because the CDTI approach procedures developed in this report rely on both lateral and vertical separation techniques to maintain positive aircraft separation, traffic conflicts and associated missed approaches will be minimized. Although each approach should have a single procedural fix for aborting an approach, general guidelines should be available for stream exit at any point in the approach. The following sections will address each CDTI approach procedure which has been developed and define these guidelines.

3.7.3 Parallel Approaches To Closely Spaced Parallel Runways

Figure 3.9 is a representation of the basic structure of this pattern as developed in Section 3.3. Recommended delay routes and holding fixes have also been depicted. This pattern presents little or no problem for a missed approach from any position in the approach since it is similar in structure to patterns which are operationally in existence today. Because of the reduced lateral separation between

the geographical confines of the airspace available for low altitude operations. These restrictions become particularly pertinent to missed approach operations because of the unplanned nature under adverse conditions of these maneuvers. Thus, ultimately, missed approach procedures must be designed to conform to the parameters inherent in the local environment. This principle does not negate the requirement for establishing guidelines applicable to the design of these procedures, however. This section will develop these procedures in an ideal, non-restrictive environment with the understanding that they may have to be modified to conform to local restrictions.

The application of specific CDTI principles to the missed approach procedure is functionally limited in most situations. The primary application will be to monitor aircraft separation both laterally and vertically. Although aircraft stream integrity could possibly be applicable in certain instances, such as rapidly deteriorating weather conditions, specific planning goals should reflect the requirement to safely maneuver an aircraft out of the traffic flow as expeditiously as possible while creating a minimal level of disruption. By emphasizing this planning approach, the impact of CDTI equipment failure in a CDTI high capacity environment can be minimized. These procedures will reflect this philosophy in that they will define specific concepts to be followed to safely maneuver an aircraft in the CDTI display. Of course, with operational equipment, the separation monitoring role should be used to enhance overall safety.

3.7.2 Universal Missed Approach Considerations

When viewed objectively, there are two phases to a missed approach procedure, safe extrication of the aircraft from the approach traffic flow and reintegration back into the flow. The reintegration phase is dependent on many facets of the local environment, including capacity levels and metering and spacing capability. The variables involved are too numerous to allow meaningful discussion at other than a local level. Ultimately, however, it does present a dilemma which will have an impact on determining the peak useable capacity of a terminal area system design.

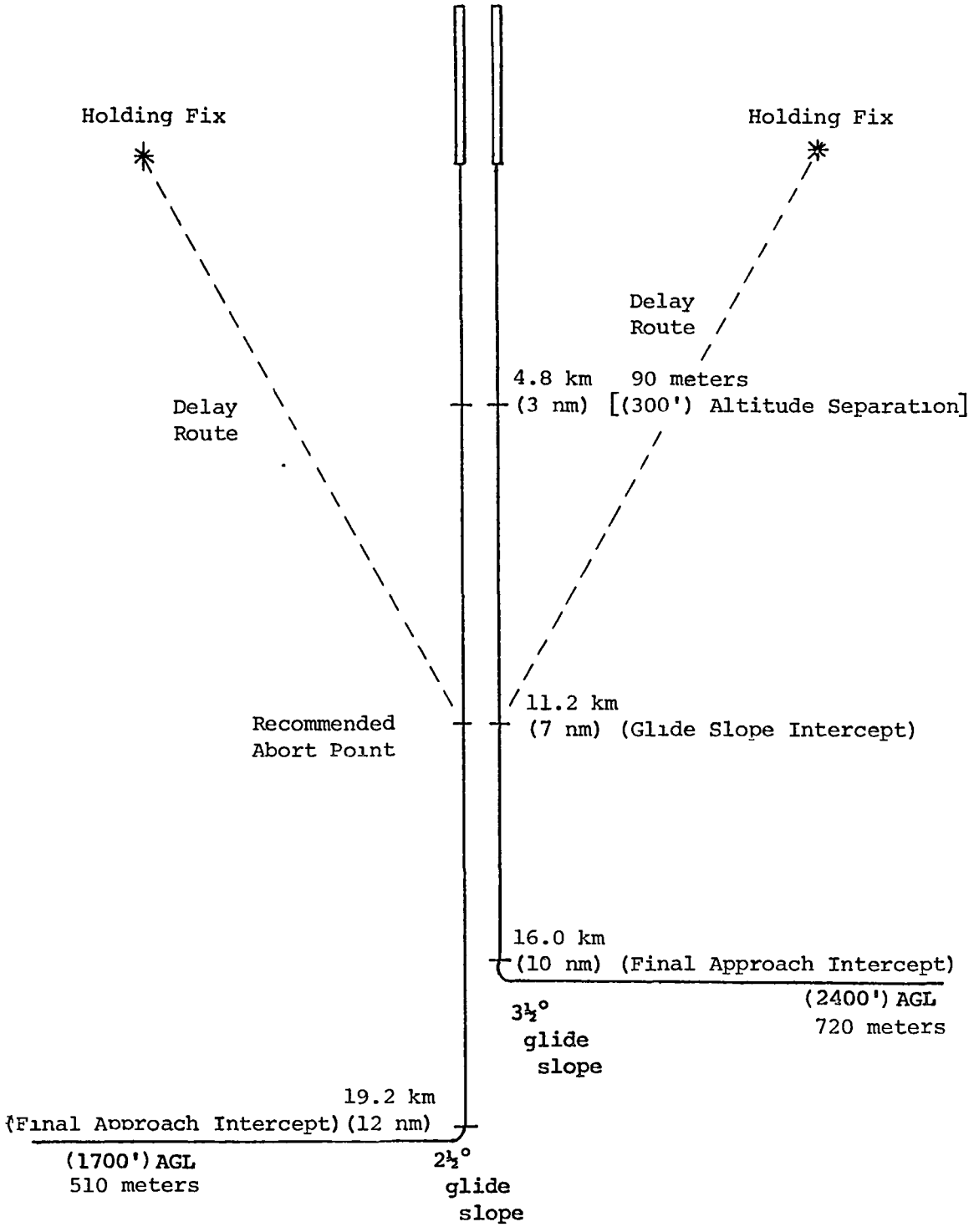

Figure 3.9 Parallel Approaches to Parallel Runways (Missed Approach)

arrival streams, added emphasis must be placed on the direction of turn during missed approach. Delay routings should be directed away from the parallel arrival stream in all cases. The holding fix can be conveniently located away from arrival and departure streams without difficulty and precise location will be dependent on local area idiosyncrasies (terrain, towers, noise abatement, etc.). Execution of the missed approach from this pattern should present no operational problems.

3.7.4 Dual Approach Paths To A Single Runway

The basic structure of this pattern, as developed in Section 3.4, is depicted in Figure 3.10 with recommended delay routes and holding fixes. Although this concept has relatively little capacity enhancement value, if it should be implemented, the missed approach implications are relatively minor. Missed approach planning should be similar in structure to that defined for parallel approaches to closely spaced parallel runways. Particular emphasis should be placed on the consideration of potential conflicts arising at the merge point and this point should be considered the primary approach abort fix. All other considerations should be conceptually the same as those which apply to dual parallel runway operations.

3.7.5 Multiple Curved Path Approaches

The complexity of this terminal area structure demands that special missed approach procedures concepts be applied during development and planning phases. Some of these concepts will necessarily be non-conventional in nature, but CDTI instrumentation should make them operationally feasible. The structure, as developed in Section 3.5, is depicted in Figure 3.11 along with recommended missed approach structures. The most complex case is presented, as this case will be the most difficult to implement operationally. Minor modification of worst case procedures will enable concept application to less complex situations.

The multiple curved path approach structure is based upon an expansion of the traditional rectangular pattern concept. Consequently,

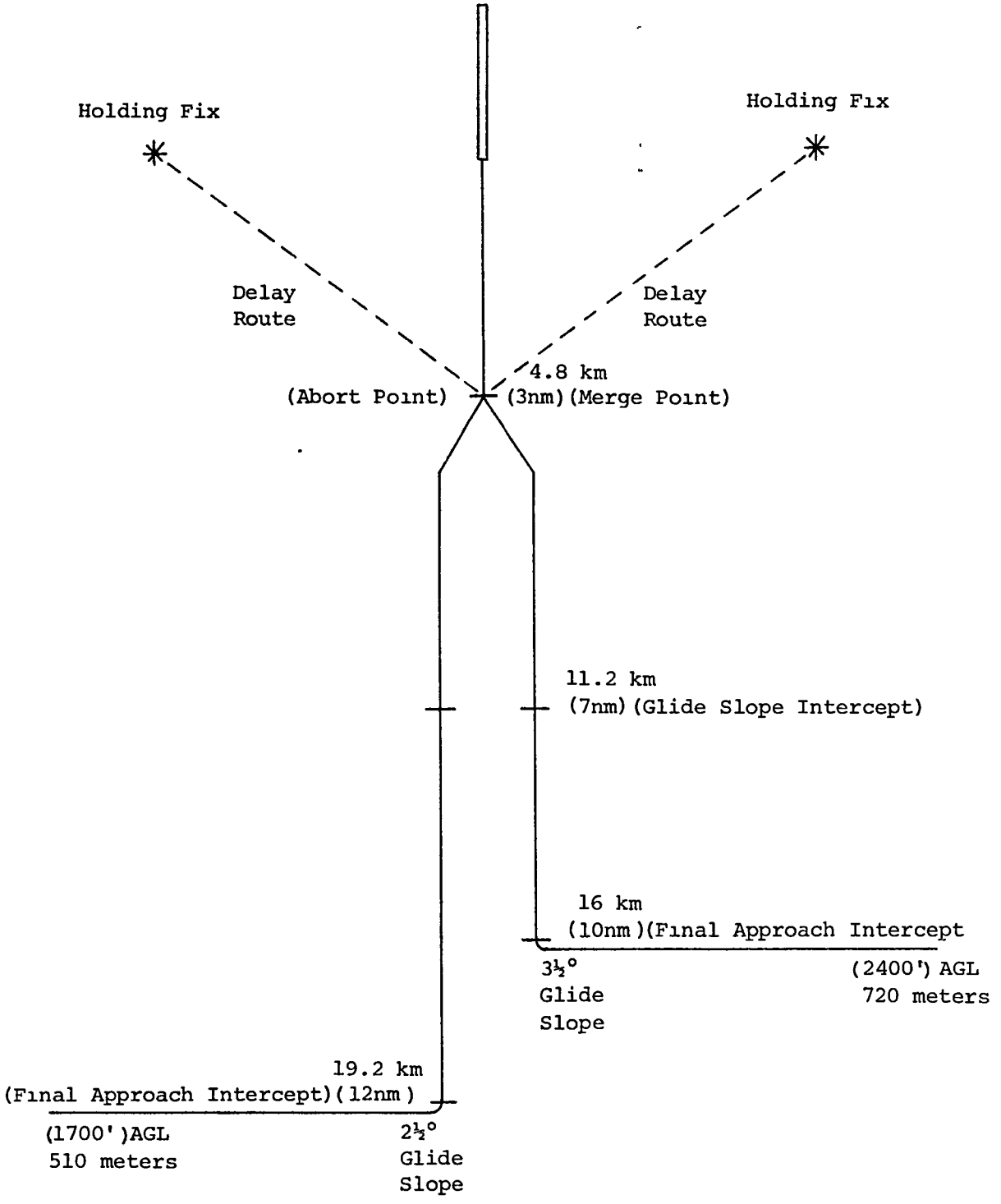

Figure 3.10 Parallel Approach to a Single Runway (Missed Approach)

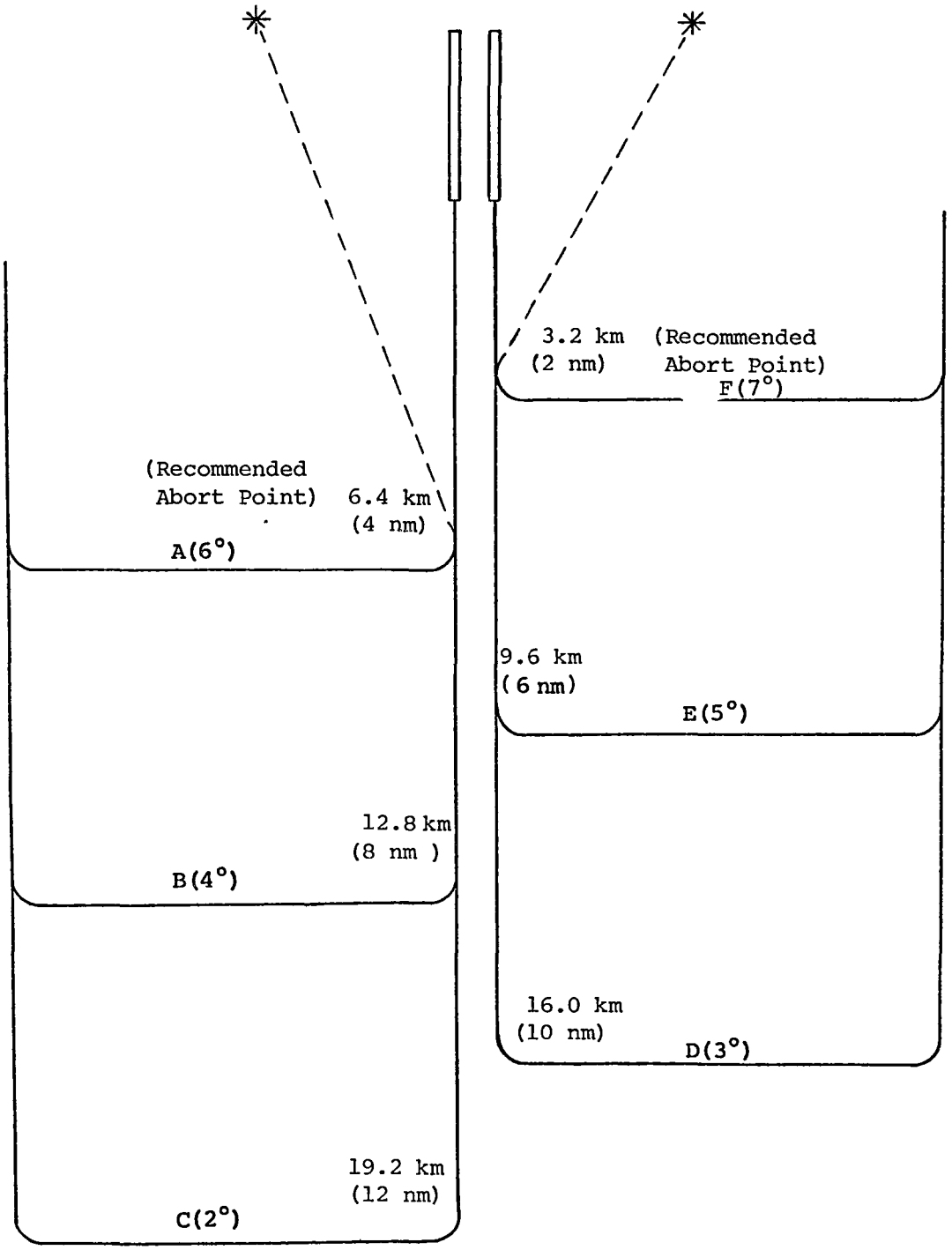

Figure 3.11 Multiple Curved Approach Path Structure

the holding fix can be placed in approximately the same relative lateral position as it is in other rectangular patterns, although positive vertical separation requirements may be more difficult to meet. This pattern, in its most complex form, utilizes altitudes from 450 meters (1500 feet) AGL to 1200 meters (4000 feet) AGL in 150 meters (500 feet) intervals. It is not reasonable, nor is it necessary, to require an aircraft to climb 1050 meters (3500 feet) after missed approach when reintegration into the approach stream is expected momentarily. Examination of the structure developed indicates that it actually consists of two components, each of which functions independently on opposite sides of runway centerline. Thus vertical separation intervals for different approach paths are actually 300 meters (1000 feet) within the same components. By maintaining component isolation during missed approach operations, 300 meters (1000 feet) separation is available during the delay routing segment and at least 150 meters (500 feet) separation from all traffic is available in the vicinity of the holding fix.

Ideally, initiation of a missed approach procedure should be delayed until after the last merge point on a particular approach path is passed. Operationally this may not always be possible, however. Thus, missed approach initiation from any point prior to the ideal abort point must be considered as a contingency. Reference to the structure depicted in Figure 3.11 indicates that aircraft on approach paths A and F theoretically always are in a position to proceed directly to the holding fix without compromising lateral clearance criteria. Aircraft on paths B and E can proceed direct as long as there is no traffic on A or F, respectively while aircraft on paths C and D can only proceed direct when there is no traffic on A and B or E and F. For this reason aircraft on the path providing the longest straight-in final approach segment should be afforded the technical right-of-way in any conflict situation. Thus there should be no need for aircraft on the C and D approach paths to initiate a missed approach prior to the ideal missed appraoch point.

These conditions, then, assure all pattern aircraft conflict free delay routings to the holding fix except for those aircraft on approach

paths B and E. Neither of these paths intercept the final approach glide slope until after merging into the straight-in final approach segment, so it can be assumed they are maintaining their respective initial altitude separation until that time. Path A merges at a hypothetical altitude of 600 meters (2000 feet) while path F merges at an altitude of 420 meters (1400 feet). Since path B and E initial altitudes are 600 meters (2000 feet) and 900 meters (3000 feet) respectively, missed approach initiation prior to glide slope intercept should consist of a climb while maintaining approach path track. This will assure vertical clearance at the final merge point. Upon reaching the abort point a conflict free delay routing is available to the holding fix. It must be emphasized that, given traffic on all available approach paths, the aircraft on paths C and D must be given priority to avoid interactions which might cause the initiation of multiple missed approaches. Likewise, aircraft using paths B and E must be afforded positive priority after glide slope intercept for the same reason.

Although these missed approach procedures appear to be complex it should be remembered that the structure itself is complex and highly dependent on the effective use of advanced metering and spacing techniques. If the assumption is made that these techniques would eliminate all merge conflicts, then there is only one missed approach point which needs to be considered, the abort point. This assumption cannot be made at this time, however, and it is somewhat doubtful whether it, in the interest of safety, should ever be made. Thus, planning should be accomplished for all reasonable contingencies.

3.7.6 Procedure Adaptation To The Local Environment

Approach planning must include as many aspects of the missed approach contingency as is feasible. Unfortunately many of these aspects are dependent upon local constraints and specific operational situations. It is hoped that the guidelines presented in this section will provide some guidance in adapting the procedures developed in this report to the local environment. These procedures have been developed for an idealized location and attention must be given to local constraints such as:

- Towers

- Terrain
- Noise abatement considerations
- Runway orientation in respect to arriving and departing traffic
- Nearby airport traffic patterns
- Local restricted areas
- Magnetic disturbances and other localized natural phenomenon

By applying these constraints to the idealized structures and concepts operationally sound CDTI approach procedures for any localized environment can be implemented.

3.8 ROUTE CROSSINGS

3.8.1 Potential Application

The ATC enroute structure, in its present form, consists of an inter-connecting network of airways which, in most cases, fly directly from one navigation facility to another. Each airway leg is a maximum of 448 km (280 nm) long, but practically, the average length is from 160 km (100 nm) to 240 km (150 nm). Whenever feasible, two routes which must cross do so at route definition navigation aids, but when this is not possible the crossing point is usually termed an intersection. Each airway handles traffic proceeding in both directions, with altitude separation being the primary means of opposite direction traffic conflict avoidance. Specific altitudes are assigned according to whether the traffic is traveling eastbound or westbound. Thus all eastbound traffic is, by design, separated form all westbound traffic, even when an intersection crossing is involved. This separation algorithm fails in the specific case where northwest bound traffic meets southwest bound traffic at an intersection, however.

In today's environment, traffic density is light enough to enable temporary altitude reassignment to be used as a primary means of alleviating this conflict in the majority of cases. Where reassignment is not possible, controllers employ radar vectors to keep crossing traffic clear. As traffic density increases, altitude reassignment will become impossible in more situations and radar vectors for separation

will become more commonplace. This will increase both controller workload and pilot uneasiness. By utilizing procedures based on the CDTI concept, the impact of both of these effects might be maintained at relatively low levels. Applying the CDTI concept to route crossings will become increasingly important as area navigation becomes more fully implemented and integrated into the ATC system because of the increased number of intersection crossings potentially inherent in an area navigation structure.

3.8.2 Procedural Concept

The route crossing procedure is a modification of the basic merge procedure. Most of the same constraints which were outlined in Section 3.1 apply to the route crossing maneuver. Essentially, this procedure is a merge maneuver which results in the merging aircraft passing through an enroute aircraft stream or at a specified distance behind an aircraft proceeding singly. For the general case, altitude separation should not be required although it could be incorporated into the procedure for specific situations if required. Like the merging procedures, clearance would be given in minicontract form with reference being made to minimum lateral clearance interval and identification of the aircraft behind which the crossing will be made. Except in the case of a tightly spaced relatively long stream, altitude separation should not be needed providing adequate lateral clearance is maintained throughout the maneuver.

3.8.3 Typical Route Crossing Procedure Display

The route crossing procedure will use the merge display exactly as described in Section 3.1. This display is reproduced as Figure 3.12 for the convenience of the reader. For this procedure the intercept of the target aircraft reciprocal track and the arc of the desired separation distance establishes the point through which "ownship" should pass rather than a finalized target position. Heading can be determined manually, by the maintenance of relative bearing, or through flight computerization, by the optional command heading indicator. In the case of crossing behind a single aircraft, the desired position indication should be considered to be a "no-closer-than" position indication. During

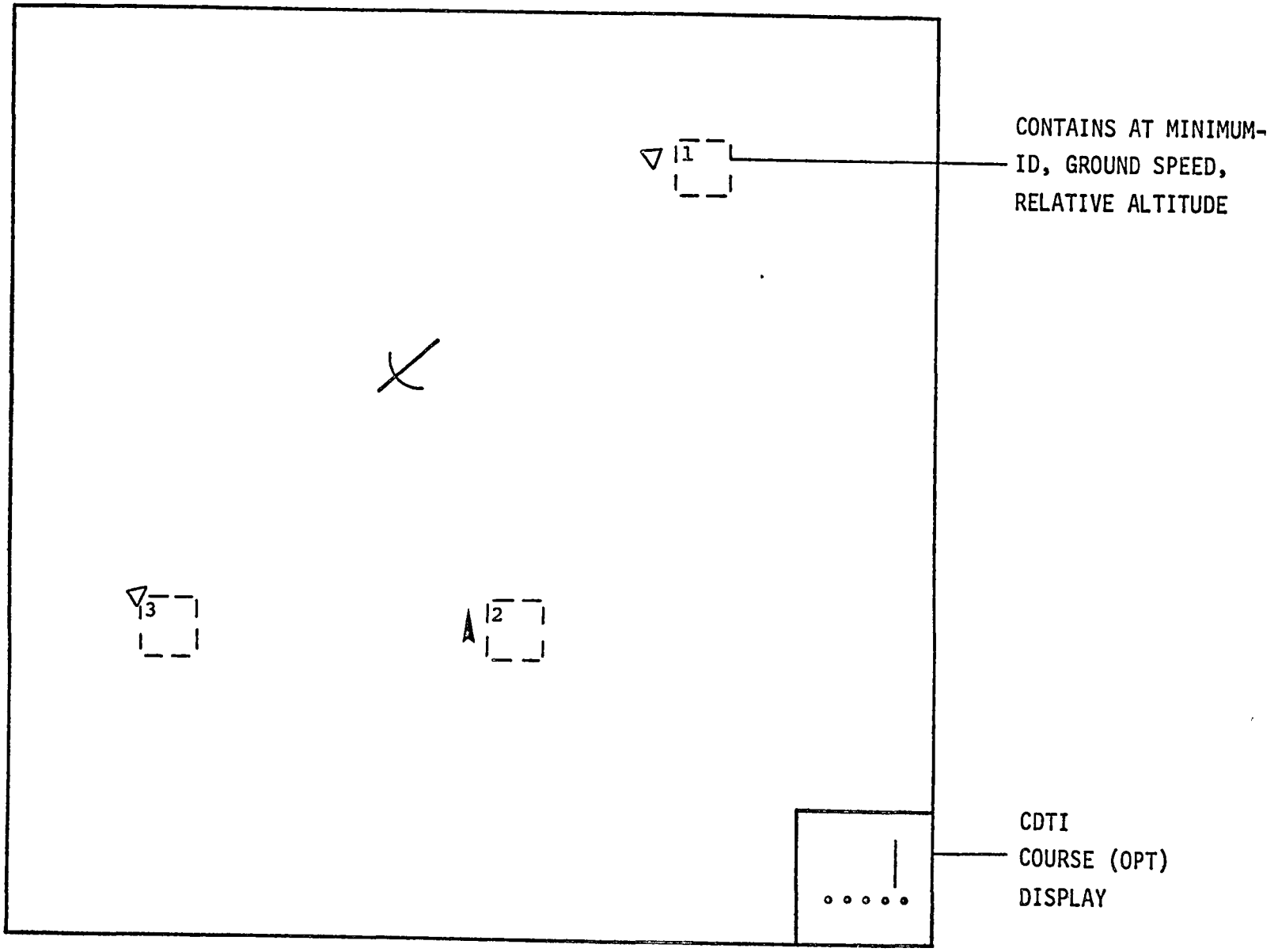

Figure 3.12 Route Crossing

stream crossing it must be considered a desired position indication.

3.8.4 Typical Crossing Clearance

"Mike 127 is cleared to cross J-24 enroute traffic stream using cockpit determined separation procedures. Pass behind Carson 447 with 4.8 km (3 nm) separation. Report when clear of J-24 traffic."

3.8.5 Operational Considerations

All operational display parameters remain the same as those discussed in Section 3.1 and will not be further elaborated on in this section. There is one operational system impact consideration which should be evaluated further however. Aircraft number 2 (ownship) in Figure 3.12 is assumed to be following a charted airway and aircraft 1 and 3 are assumed to be part of a stream following another airway. Depending on the timing involved "ownship" will, in all probability, be required to make minor track deviations from airway centerline in order to safely cross at the designated separation interval. How much deviation will be required is unknown at this time and in fact depends on several localized conditions, such as crossing angle and relative speed of all aircraft involved.

Airway route widths vary depending on specific requirements, but are designed with the assumption that user aircraft will attempt to maintain route centerline. During the CDTI route crossing procedure, navigation is not referenced to published routings but is referenced to an assigned crossing point in a moving aircraft stream. The overall impact of this interaction should be tested and evaluated thoroughly before implementation. Additionally, results of that testing should be formulated into guidelines for the establishment of route corridor widths in the immediate vicinity of intersections. These guidelines will become additionally important as airspace demand indicates the need for the development of alternate parallel airway routes.

3.8.6 Comments

The CDTI route crossing procedure is a straightforward extension of the merging procedure. With the exception of possibly requiring a slightly larger corridor width in the immediate vicinity of route

intersections, negative system impact should be minimal, while benefits will be significant particularly as airspace demands increase. With the development and implementation of advanced metering and spacing techniques in the future ATC system, route width expansions can conceivable be minimized.

3.9 WEATHER AVOIDANCE DEVIATION

3.9.1 Potential Application

Through the application of imaginative thinking, the CDTI concept can make significant contributions to the problem of weather penetration. Flight in the immediate vicinity of thunderstorms is strongly discouraged and all pilots are instilled with the idea of avoiding them. Under certain conditions this is difficult to do. Avionics manufacturers are currently developing equipment designed to detect severe weather, but this equipment is far from infallible. Weather radar is capable of detecting precipitation, but often times the most violent portions of thunderstorm cells are not associated with precipitation. Attenuation can also be a problem, particularly in the case of imbedded storms. Ground based ATC radars are also an unreliable source of weather information because they are polarized to minimize weather returns in order to enhance the primary aircraft returns needed for the traffic control function.

Perhaps the best method of avoiding severe weather is through direct observation, either by the individual pilot or by other aircraft which have recently transited the area. When imbedded storm cells, usually associated with occluded fronts, are involved visual observation is impossible. In this case the best information available is from those aircraft which are currently penetrating the front. Although controllers freely distribute information on known weather phenomena and often will attempt to accommodate individual aircraft with radar vectors through or around widespread areas of reported high storm activity, this accommodation significantly increases their workload and puts an added burden on them. The development of a concept whereby an aircraft could, through cockpit instrumentation, duplicate the path of an aircraft which has already successfully penetrated a line of cells would enable much of this

burden to be lifted from the controller.

3.9.2 Procedural Concept

The primary requirement for weather penetration under this concept is the ability to reproduce, in the cockpit, the track of aircraft which have recently successfully penetrated a line of storm cells. The spacing procedures, as developed in Section 3.2, fulfills the requirement very well. Even in conditions of relatively low traffic flow, manually input spacing values can be adjusted to present a meaningful cockpit display. Hypothetically, if a frontal line had been penetrated five minutes prior to the arrival of "ownship" by Carson 447, the CDTI spacing display could be set up to follow Carson 447, with 56 kn (35 nm) spacing (assuming 420 knots ground speed). This will establish a "position-box" (as described in Section 3.2) which will in effect follow the target aircraft track through the weather line. Spacing distances can be adjusted to approximate "ownship" current position longitudinally along track. Controller workload is decreased, as navigation is based on cockpit presentations and not controller initiated radar vectors.

Ideally, this procedure should be used in conjunction with an airborne weather radar display to more fully evaluate the position of cells along a frontal line. It is possible that a hole could close in a relatively short time period, particularly when it is associated with a dynamic fast moving front. Fortunately, occluded fronts are generally slow moving and thus are relatively stable in composition. Even so, separation between aircraft using CDTI as the sole means of frontal penetration should not exceed ten minutes. This value should be further investigated and readjusted as required prior to procedure implementation, however.

3.9.3 CDTI Weather Deviation Clearance

"Mike 127 is cleared to deviate to the south for weather avoidance. Recommended deviation track is behind Carson 447 currently 56 km (35 nm) ahead of you. If further deviation is required contact me this frequency".

3.9.4 Typical Weather Deviation Display

The spacing procedure display, as presented in Section 3.2, presents all of the elements which are required to perform this procedure. Figure 3.13 is a reproduction of that display presented here for the reader's convenience. This depiction illustrates a 16 km (10 nm) range factor when a 80-120 km (50-75 nm) range might be more appropriate for this procedure in the general case. None the less the principles remain the same as for the spacing display.

3.9.5 Operational Considerations

Perhaps the most important consideration is the stability and/or predictability of the cell composition of the thunderstorm activity associated with storm fronts. Cold fronts are generally associated with dynamic rapidly changing conditions, where cells are generated and dissipated with little or no warning in a relatively short period of time. Fortunately, this type of front is also generally associated with visual flight conditions both immediately before and immediately after frontal passage. This enables the use of direct visual observation as the primary means of establishing the safest route to follow when transiting a line of thunderstorms during day light hours. During the hours of darkness this type of weather generally diminishes in intensity, creating less of a direct hazard to flight.

The most difficult type of storm activity to safely penetrate is the activity associated with occluded frontal systems. This is because the IFR weather generally associated with the area around the frontal system prohibits direct observation of the cellular composition of the frontal activity. Weather radar attenuation characteristics make interpretation of airborne radar displays difficult at best in this type of environment. The most reliable information is the recent experience of other aircraft in the immediate vicinity, with the most useful data being the historical track of aircraft which have recently transited the area in question. Often times the flight conditions "behind" the frontal activity are much better than that "ahead" of it and a pilot report can indicate a safer routing after the line of activity has been transited. Historical track data can serve as a reference for

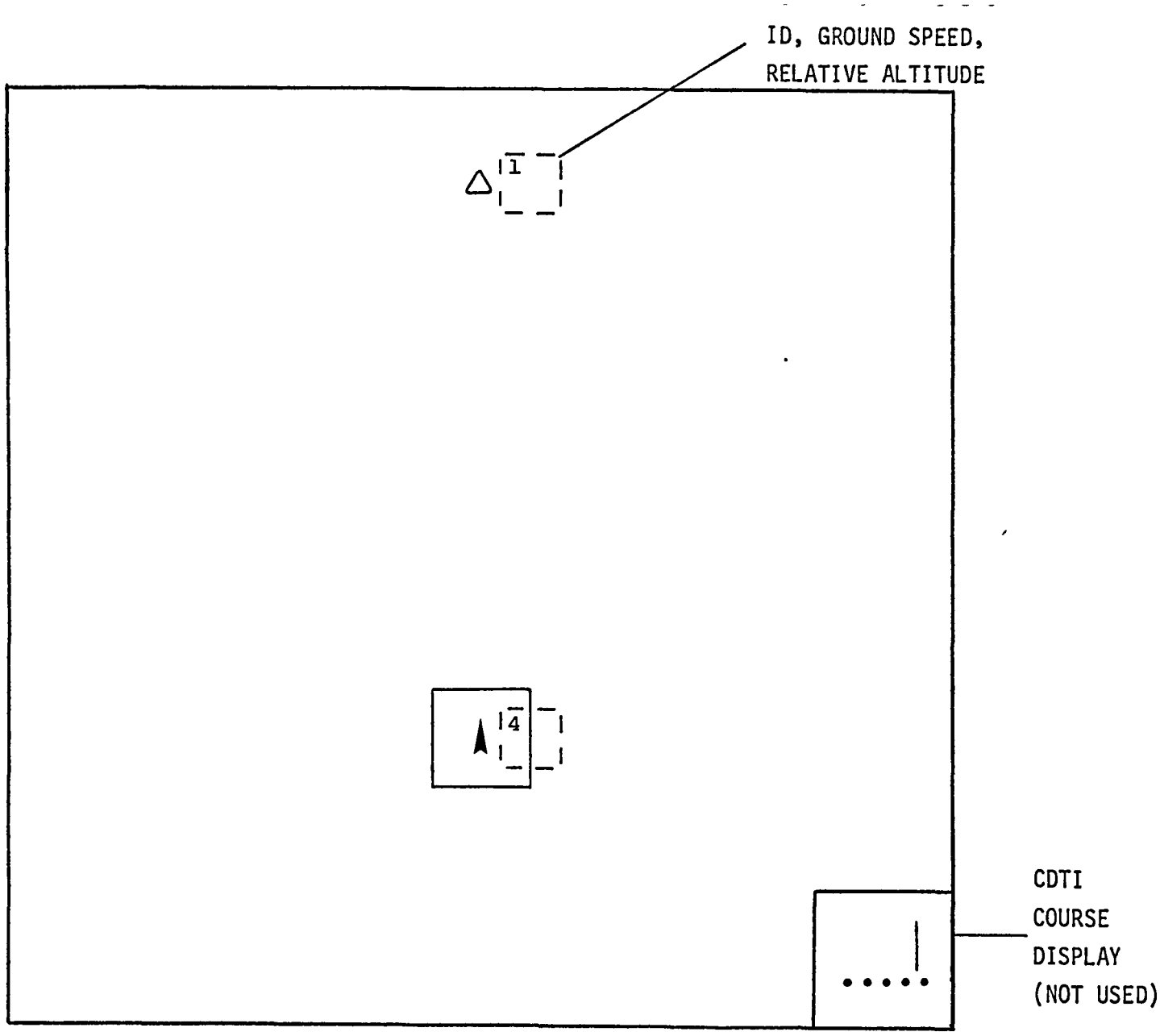

Figure 3.13 Weather Avoidance Deviation

this improved routing. Additionally, occluded fronts are generally associated with stability of cell composition, a characteristic which makes historical tracking data even more attractive as a source of routing information. The composition of all frontal systems change over time, even in the most stable system, and time is a determining factor in the applicability of historic tracking data to the current situation. The upper safe limits for this factor are unknown at this time and further research should be conducted in this area to determine these limits.

3.9.6 Comments

The CDTI concept has the potential for fulfilling the requirements of an immediate need in the area of weather avoidance navigation. Technological improvements may make this function obsolete but the procedure developed here could be used to establish a point of reference even in an ATC environment consisting of highly evolved weather detection avionics. If technological improvements do not evolve within the time schedule predicted, the CDTI weather avoidance deviation procedure could be used to provide information concerning the safest means of transiting areas of potentially hazardous thunderstorm cells associated with frontal weather systems. The potential implications of this problem and the potential benefits which could be derived from this procedure, make it a primary candidate for early testing and implementation. Development should parallel the basic merging and spacing procedures defined in Section 3.1 and 3.2.

4.0 DISPLAY CHARACTERISTICS

The successful implementation of the procedures developed in this study depends on the effective cockpit presentation of related parameters. The parameters have been individually defined in the preceding sections dealing with specific procedures. This section will attempt to aggregate all of these display requirements and define some of the external characteristics of the display unit which will incorporate these requirements. This conception is based solely on the requirements definition developed in this study and exhaustive research has not been accomplished to determine the need for additional functions peripheral to the requirements of the procedures developed in Section III. The peripheral functions should be relatively easy to accommodate and include such things as mode annuciation and failure warning devices. Specific integration of the functions will be left to the operational development of the CDTI system.

The procedures outlined in this study require three basic display modes.

- Merging
- Spacing
- Ground Monitor

Additionally, a switch for inputing flight phase (enroute or terminal area) should be incorporated, primarily for flight director scaling to meet operational/environmental error budget tolerances. The flight phase switching would affect only the merging and spacing displays, unless a meaningful ground monitor display for enroute operations can be developed. No role has been envisioned for this combination to date, thus enabling functional growth capability for future instrumentation demands. Plausible candidates for this role include ground mapping or large scale enroute traffic display functions.

4.1 MERGING DISPLAY

The basic merging display was described in detail in Section 3.1 and is reproduced here as Figure 4.1 for the convenience of the reader. This depiction presents only those components which are essential to the

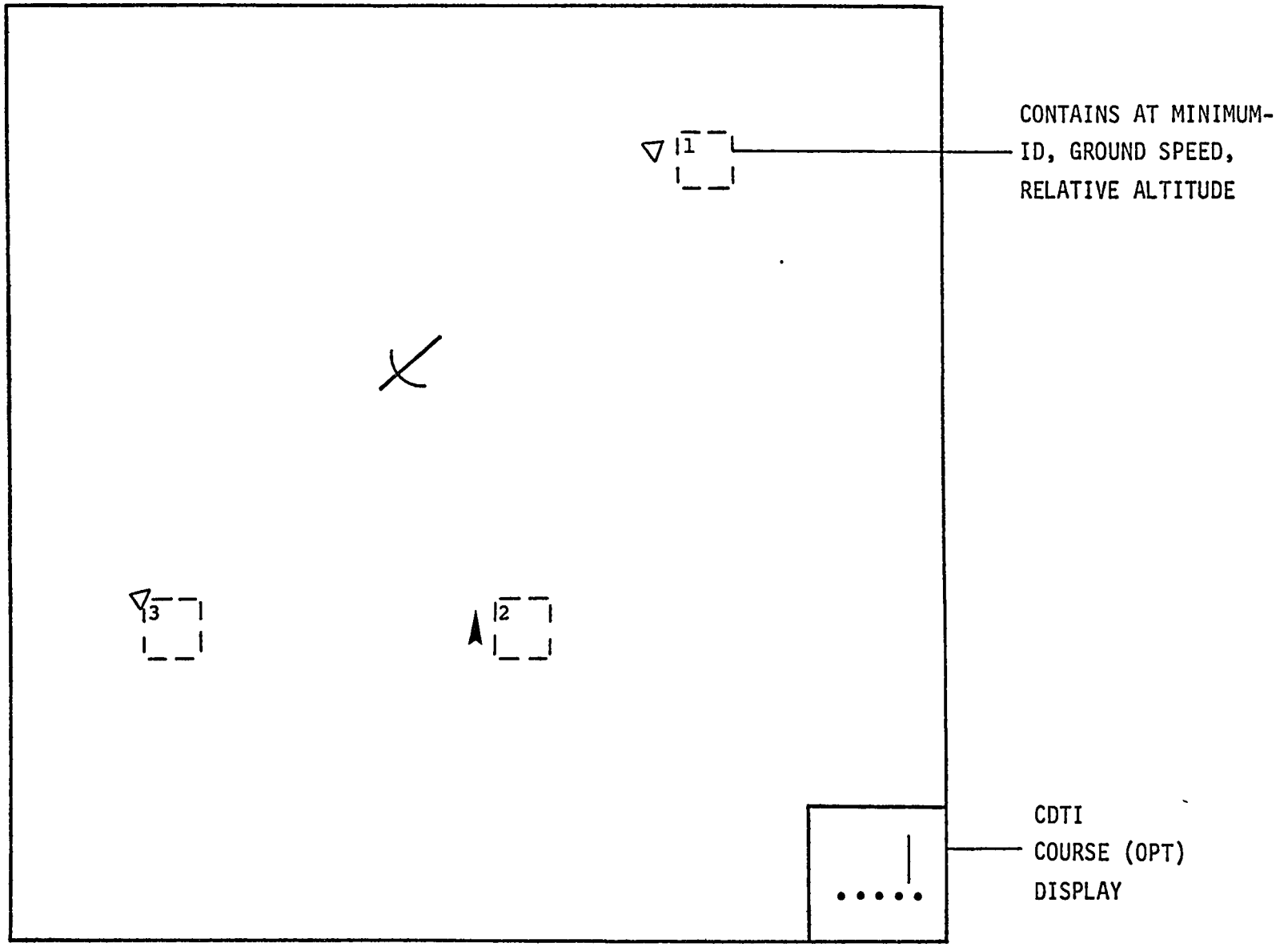

Figure 4.1 CDTI Merge Display

application of the merging procedure and additional information can be presented on the display if desired. Introduction of new display data should be limited, however, so that the display field does not become cluttered and illegible. The following data components have been defined as essential to the merging procedure:

- Position of "ownship"
- Position of all other traffic within CDTI range and altitude limits
- Identification blocks for all displayed aircraft
  - Identification
  - Speed Reference (preferably ground speed)
  - Altitude Reference (preferably relative altitude)
- Indication of desired position in traffic stream

In addition to these essential components the computer generated optional CDTI course display is also depicted in Figure 4.1

The "ownship" position should be a permanently located non-moving element of the display. It should be located about two-thirds of the way down the display face to accommodate increased forward visibility while maintaining adequate visibility to the rear. This element should be centered laterally to enable equal visibility to either side. Thus, when a 16 km (10 nm) range is displayed, forward visibility is approximately 11.2 km (7 nm), with 4.8 km (3 nm) to the rear and 8 km (5 nm) to either side.

The position of all traffic which falls within established range and altitude limits should be displayed relative to the "ownship" position. Range limits are determined by the physical dimensions of the display and the range setting. Altitude limits are established by the altitude filter which can be variable, based on cockpit inputs, or preset by the manufacturer. Predicted course vectors would prove to be beneficial in display interpretation and should be considered as a potential item for display element expansion.

Each aircraft displayed, with the possible exception of "ownship" should have an identification data block associated with it, displaying identification, a speed reference, and an altitude reference. The data

block characters should be large enough to be readily discernable yet small enough to avoid unnecessary display clutter and the aircraft/ data block association should, at all times, be readily apparent.

The elements discussed thus far have parallel counterparts in other display modes. The next to be discussed, the desired position indicator, is unique to the merging display. The merging procedure is designed as a means of maneuvering the "ownship" aircraft to a position described as a specified distance behind (in trail) a specified aircraft. This position is indicated graphically on the display as the intersection of the reciprocal track of the designated aircraft and the arc of the specified distance as measured from the target aircraft. The resulting display is a cross or an "X" depending on orientation. Although the reciprocal track of the target aircraft is an entering argument for position determination, historical track could be substituted in its place. Reciprocal track computation has the advantage of anticipating the impact of turning maneuvers on the merging operation. This advantage must be evaluated against the additional software requirement it incurs, as the spacing procedure requires historical track data for its computation. Final determination of the method to be implemented will depend on equipment design constraints when the system is tested.

The CDTI course display, shown in the lower right corner of the display in Figure 4.1, is a computer generated command heading indicator which commands a direct intercept heading to the desired position based on relative position and speed determinations. This display element is optional, as the information it supplies can be manually computed by the flight crew from the raw display data available to them. If incorporated into the display this element should function much like a standard course deviation indicator (CDI) with the exception that the desired course would be computer generated rather than manually set by the flight crew.

The CDTI merging display has several applications both in the enroute environment and in the terminal area environment. The design presented here is only the basic design incorporating only those elements which are considered essential to the accomplishment of the merging procedure.

Undoubtably, operational testing will uncover the need for further refinements and modifications which will enhance the basic CDTI merging concept.

4.2 SPACING DISPLAY

The basic spacing display was described in Section 3.2 and is redepicted here as Figure 4.2 for the convenience of the reader. Many of the display elements present in the merging display are common to the spacing display, although some of the computation algorithms are slightly altered. Both display designs are flexible at this stage of development, thus accommodating either functional integration or growth capability. The display system discussed here reflects the requirements of the spacing procedure defined in Section 3.2. The following elements are considered to be essential to this procedure.

- Position of "ownship"
- Position of all other traffic within CDTI range and altitude limits
- Identification blocks for all displayed aircraft
  - Identification
  - Speed Reference (preferably ground speed)
  - Altitude Reference (preferably relative altitude)
- Position box displaying desired aircraft position in the stream.

All spacing display elements are identical to those elements defined for the merging display with the exception of the desired position indication. Additionally, the optional CDTI course display is nonfunctional. Because of the potential impact of the "accordion" effect and its associated dynamic instability, the spacing display desired position element has been changed from a point referenced to an area referenced concept. This element, termed the position box, defines an area of acceptable position within which the "ownship" aircraft is free to move. The dimensions of the box can either be variable, as programmed by the flight crew, or fixed, as preset by the manufacturer. Flight phase conditions can be established by the

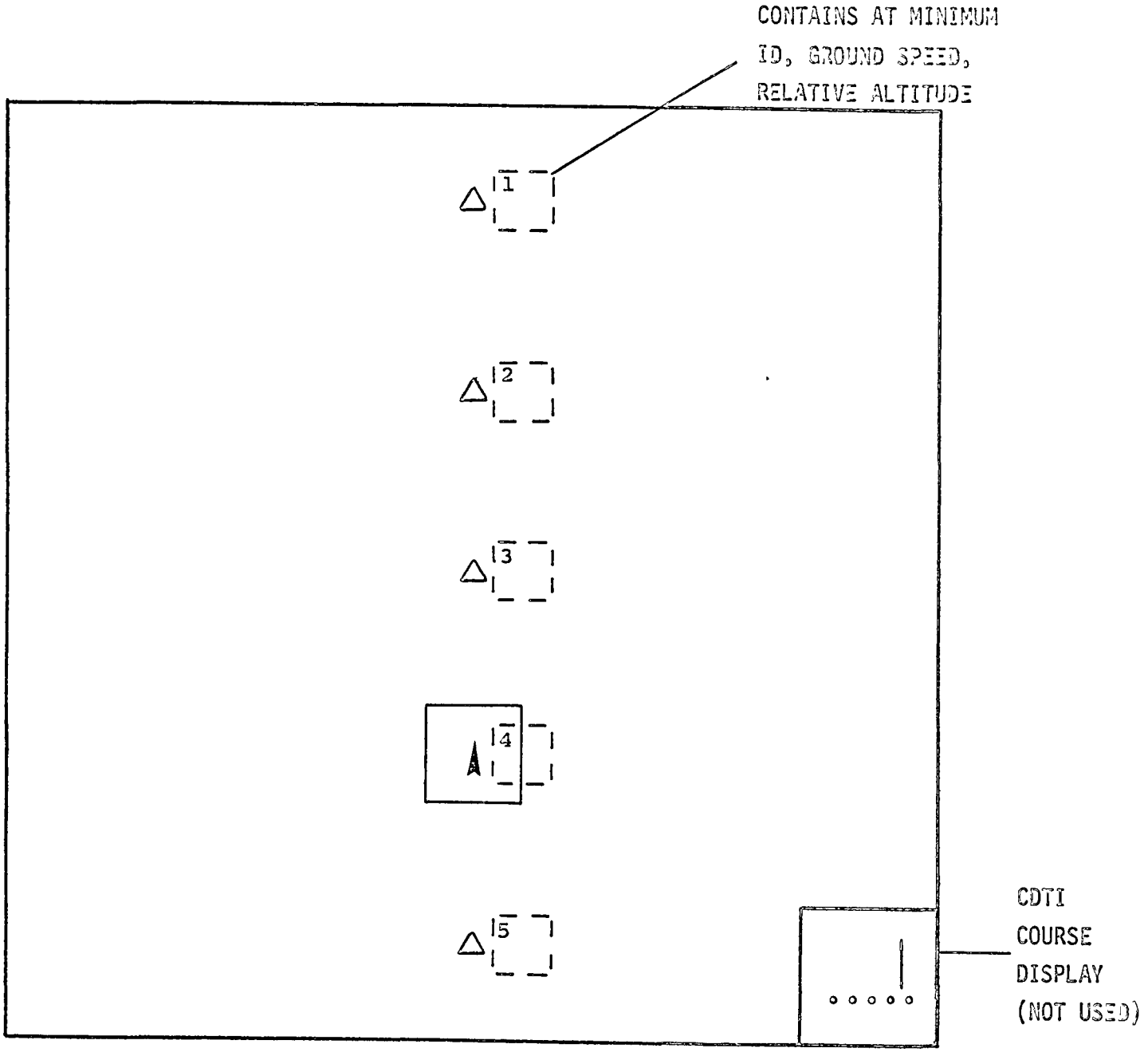

Figure 4.2 CDTI Spacing Display

position of the flight phase selector (see Section 4.4) or by data uplink code. The center of the box is defined as the intersection of the historical track of the target aircraft and the desired spacing distance, as programmed by the flight crew, measured from the target aircraft. This intersection represents the theoretically ideal position while the position box itself contains the set of all acceptable positions. The final dimensions of the box will depend upon operational test results and anticipated applications of the system, but the values given above are the initial recommendations.

The spacing display has been designed to accommodate functional intgration with the merging display to the maximum extent possible without diminishing the operational value of either display. Operational testing will determine whether the two designs can be more fully integrated or should be more functionally isolated.

4.3 GROUND MONITOR DISPLAY

The ground monitor display concept is unique in comparison to the merging and spacing display concepts. As described in Section 3.6, the ground monitor role is designed to display the ground traffic situation at a terminal airport facility. The proposed display is reproduced as Figure 4.3 to facilitate ease of reference. As conceived in this report the ground monitor display consists of the following elements:

- A plan view of the airport being monitored
- Position of all airborne aircraft within range of the display
- Position of any aircraft occupying the assigned landing runway
- Position of all aircraft occupying the specified taxiways
- Identification blocks for all displayed airborne aircraft
  - Identification
  - Speed Reference (preferably ground speed)
  - Altitude reference (preferably height above the airport)
- Identification block for all aircraft occupying the assigned runway
  - Identification

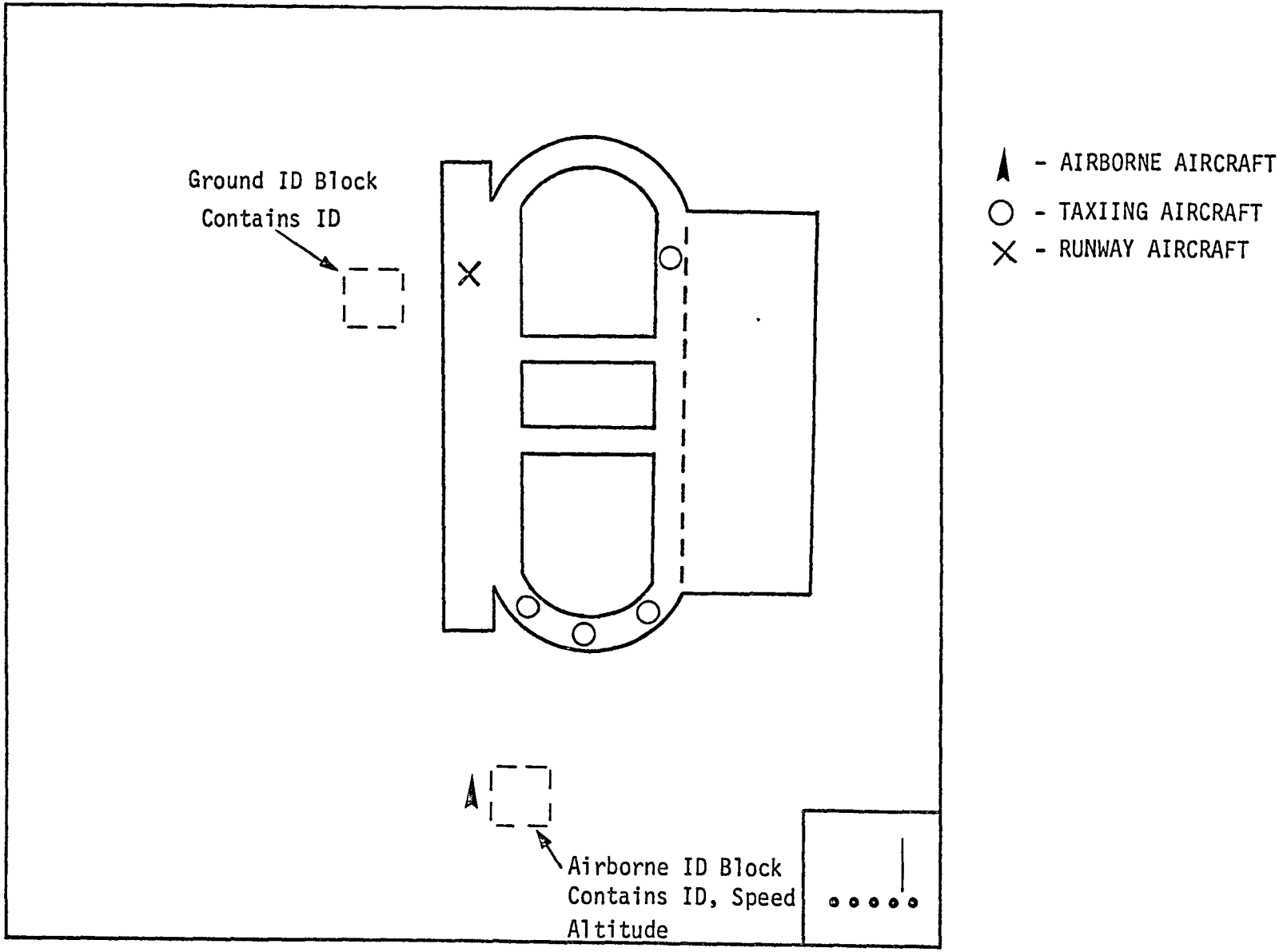

Figure 4.3 Ground Monitor Display

These elements constitute the minimum requirements for cockpit evaluation of the airport traffic situation. Whereas the display reference for all other modes of the proposed CDTI configuration is the position of "ownship", the display reference for the ground monitor mode are specific airport lat/lon coordinates. Thus, when "ownship" is portrayed on this display, it has all of the characteristics of any other aircraft which is portrayed and the aircrew has the opportunity to view a particular situation from a third person viewpoint. It is possible that this capability will be a significant aid in the proper evaluation of a traffic situation, although this possibility should be substantiated in a comprehensive test program.

The rapid evaluation of a ground traffic situation requires that displayed aircraft be categorized according to their relative impact on the total runway system. Different symbologies should be used to represent each category. Three categories have been defined for this display; airborne aircraft, represented by Δ, aircraft occupying the assigned runway, represented by X; and aircraft occupying taxiways and unassigned runways, represented by O. Aircraft on parking ramp areas were considered unimportant to the immediate ground situation and are therefore, not displayed. Identification data blocks are associated with airborne and runway aircraft. Both include aircraft identification but only airborne aircraft display associated speed and altitude data. Taxiway aircraft have no data blocks associated with them. Every attempt has been made to reduce the number of data blocks present on the display at any one time in order to avoid display clutter to the maximum extent possible. Additional data block information can have a positive impact on the evaluation of the traffic situation.

Although no control procedures have been specifically defined for the ground monitor role, this display has the potential for supplying the information needed to perform IFR operations which closely approximate current VFR operations, particularly when operating in the immediate vicinity of the terminal airport. Potential benefits include a reduction in ground accidents, development of wake vortex

avoidance procedures, improved cockpit understanding of the current traffic situation, reduced runway occupancy time, and an increase in pilot assurance factors.

4.4 FLIGHT PHASE SELECTOR

In its most basic form, the flight phase selector is a two position toggle switch with an enroute position and a terminal area position. The physical nature of the switch is unimportant and the switch can be a wafer switch, pushbutton, or any other type of manually operated switching mechanism. The primary purpose of this selector is to scale displays in order to conform to reduced terminal area error budget criteria. When using the merging display mode, terminal area selection will reduce the full scale deflection value of the CDTI course display to one half of its enroute value. This concept is similar to the one in common use today when displaying VOR and ILS courses on many types of horizontal situation indicators. The terminal area selection when using the spacing display will primarily affect the dimensions of the position box. For terminal area operations this box should be no larger than 0.8 km (1/2 nm) on a side. Larger dimensions are necessary for enroute operations. Depending on the error budget constraints of specific terminal area procedures, the dimensions of the position box may have to be reduced even further for terminal area operations. Decreasing the size of the position box increases the potential impact of the accordion effect, however, so operational tradeoffs should be thoroughly evaluated.

Enroute applications have not yet been determined for the ground monitor display and, until they are developed the flight phase selector should be non-functional when using this mode. Suggestions for plausible enroute displays include:

- Ground map
- Airways map
- Programmed RNAV routing
- Aircraft enroute performance computations

These suggestions do not relate to the CDTI concept however, and will not be further developed in this report. As described here, the enroute position of the ground monitor mode will remain undefined and serve as functional growth capacity.

4.5 DISPLAY SUMMARY

The display system described in this section is a basic recapitulation of the displays developed in Section 3. Only those elements which relate to the successful performance of the described procedures have been included in this discussion. There are many additional elements which, if included, could supply auxiliary data to the aircrew. Some of these elements should be included in the CDTI display, but selection of these elements is beyond the scope of this report. Undoubtably, the proposed test program will identify those auxiliary elements which are most beneficial to the aircrew.

5.0 RECOMMENDED PROCEDURAL TEST SEQUENCING

The successful implementation of the CDTI concept into the ATC system will depend upon the results of a comprehensive test and evaluation plan. This plan should emphasize aircraft safety and efficiency measures and should evaluate the impact of the proposed operational procedures on aircrew workload, particularly during flight phases traditionally associated with high workload levels. Acceptance of the CDTI concept by controlling agencies will be encouraged by the application of comprehensive test standards to each of the proposed procedures in a realistic environment.

Once comprehensive test standards have been established, the sequencing of specific procedures to be tested becomes crucial to the success of the program. The basic procedures, merging and spacing, should be evaluated and, if required, modified first, since these procedures are used as components of the more complex procedures. Interactive roles in complex procedures should be considered whenever procedure modification is required. Once acceptable versions of these procedures have been established, the sequence of testing other procedures should be based on procedural complexity and the expected stringency of the ATC environment into which the procedure will be introduced. For this reason, it is recommended that the weather avoidance and route crossing procedures be the next ones to be evaluated. Finally the terminal area procedures should be tested beginning with the simplest structure and working to the more complex. Any procedural deficiencies which are uncovered should be corrected by procedural modifications. Care should be taken to avoid unnecessary modification which add to concept complexity, however.

This procedure test sequence is recommended primarily for three reasons. The first is that the basic procedures should be perfected prior to their incorporation into more complex procedures. Second, procedure modifications can be accomplished less easily when dealing with complex structures. Third, confidence in the CDTI concept can be promoted by successfully testing operational procedures. The more

basic those procedures are the greater the probability those tests will be successful.

Although a listing of the components of a comprehensive test plan is beyond the scope of this report, the following recommendations are presented as components which should be considered:

- Simulator testing
  - Realistic portrayal of technical environment being simulated
  - Realistic pilot/controller interface
  - High density as well as low density traffic models
  - Realistic aircraft mixes
  - Non-CDTI traffic components as well as CDTI equipped components
  - Measurement of long term workload effects as well as short term effects
  - Impact of blunders on overall system structures
  - Pilot/controllers stress reaction tendencies
- Flight testing
  - VFR conditions with simulated IFR operations
  - Test locations indicative of variation in traffic densities
  - Variation in types of terminal areas utilized
  - Crosssection of ratings held by subject pilots

These considerations are just a few of the components needed to design a comprehensive test plan. The key to test plan design is the incorporation of realism into the test scenario. The closer the test scenario comes to the real world environment, the more valid the results and conclusions will be.

6.0 SUMMARY

The CDTI Candidate Procedures Study is a small segment of the CDTI concept development program. Limited in scope, the study objective was to develop specific candidate procedures which related directly to the CDTI concept. These would then be the strawman procedures used in proof of concept testing, the next major segment of the program.

Because it was necessary to maintain realism, ATC system definition was required. Near term references and far term references were considered as the basis of this definition and, because of the unpredictability of research and development time schedules, a technology referenced base was chosen rather than a time referenced base. Aircraft mix and traffic demand was considered as annual rates of change thus enabling easy translation into the technology referenced system definition.

The next step in the development process was establishment of those capacity enhancement techniques based on the CDTI concept which were worthy of being expanded into procedures. Specific procedures for each technique were then developed and an analysis of operational impact on the near term and far term ATC systems was performed. Where necessary to the procedure display elements were identified and typical display suggestions were depicted. After all procedures were presented and analyzed, the display requirements were aggregated and presented separately. Finally a recommended sequence of procedures to be tested was introduced, in order to transition the results of this study more easily into the next program phase, operational testing.

The CDTI concept has the potential to significantly increase current capacity levels if implemented effectively. CDTI and its corrollary, distributed management, can enable ATC system capacity levels to keep pace with the growing demand by user groups for more efficient use of the available airspace.

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1 Report No	2 Government Accession No	3 Recipient's Catalog No
NASA CR-165673		

4 Title and Subtitle	5 Report Date
CANDIDATE CDTI PROCEDURES STUDY	January 1981
	6 Performing Organization Code
7 Author(s)	8 Performing Organization Report No
R. E. Ace	
9 Performing Organization Name and Address	10 Work Unit No
Systems Control, Inc. (Vt.) Champlain Technology Industries Division 2326 So. Congress Avenue West Palm Beach, FL 33406	11 Contract or Grant No NAS1-16247
12 Sponsoring Agency Name and Address	13 Type of Report and Period Covered Contractor Report
National Aeronautics And Space Administration Washington, DC 20546	14 Sponsoring Agency Code

15 Supplementary Notes

Langley technical monitor: Gene Moen
Final Report

16 Abstract

The CDTI concept has the potential for increasing airspace capacity by involving the pilot in the separation control loop. Prior to realization of this goal specific definitive procedures must be developed, tested, and proven to be operationally safe and practical. This report presents some candidate options to be considered for this development. Both enroute and terminal area procedures are considered and, in many cases, a technologically advanced ATC structure is assumed. Additionally, minimum display characteristics recommended for each of the described procedures are presented. Finally, recommended sequencing of the operational testing of each of the candidate procedures is presented.

17 Key Words (Suggested by Author(s))	18 Distribution Statement
CDTI Approach Procedures Enroute Procedures Displays Distributive Management	Unclassified - Unlimited Subject Category 03

19 Security Classif (of this report)	20 Security Classif (of this page)	21 No of Pages	22 Price*
Unclassified	Unclassified	77	A05

N-305

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