MTR-87W203

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ESTIMATES OF POTENTIAL INCREASES IN AIRPORT CAPACITY THROUGH ATC SYSTEM IMPROVEMENTS IN THE AIRPORT AND TERMINAL AREAS

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OCTOBER 1987

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Springfield, Virginia 22161

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
SYSTEMS STUDIES AND COOPERATIVE PROGRAMS
Washington, D.C. 20591

NOTICE

Technical Report Documentation Page

1. Report No. FAA-DL5-87-1	2. Government Accession No. AD-A188 533	3. Recipient's Catalog No.
4. Title and Subtitle Estimates of Potential Increases in Airport Capacity Through ATC System Improvements in the Airport and Terminal Areas		5. Report Date October 1987
		6. Performing Organization Code
7. Author(s) John E. Lebron		8. Performing Organization Report No. MTR-87W00203
9. Performing Organization Name and Address The MITRE Corporation 7525 Colshire Drive McLean, Virginia 22102		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. DTFA01-84-C-00001
12. Sponsoring Agency Name and Address Department of Transportation Federal Aviation Administration Office of Systems Studies & Cooperative Programs Washington, D. C. 20591		13. Type of Report and Period Covered
		14. Sponsoring Agency Code ADL-5
15. Supplementary Notes		

16. Abstract

This report presents the results of a study performed to estimate the potential increases in airfield capacity that might result from improvements in airfield and terminal-area operations. The purpose of the study is to help the Federal Aviation Administration and industry understand the expectations and limitations of airport capacity increases achievable through technical solutions. The focus of the study is on how much of an operational improvement is necessary to increase capacity, not on how new technology results in operational improvements. The study methodology is to identify key parameters, such as interarrival separation minima and runway occupancy time, that are susceptible to change through technical Air Traffic Control system improvements; hypothesize changes in the parameters that may be achieved; and compute the capacity increases that would result from such changes. Upper limits on the potential capacity increases that can realistically be expected are also computed.

17. Key Words Airports, Airfield Capacity, Air Traffic Control, Visual Flight Rules, Instrument Flight Rules	18. Distribution Statement **Available to the Public through the National Technical Information Service, Springfield, Virginia 22161.**

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

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

ACKNOWLEDGMENTS

The author wishes to acknowledge the contributions of several people to the development of this report. Special thanks go to F. Amodeo of MITRE, for his thorough review of the technical content of the document; to R. Rucker of MITRE, and S. Poritzky of the Federal Aviation Administration, for their comments on how best to present, in an understandable fashion, the complex information contained herein; and finally, to the secretarial staff and especially D. Dick, who diligently produced the many revisions required in production of this report.

EXECUTIVE SUMMARY

OVERVIEW

This report presents the results of a study performed to estimate the potential increases in airfield capacity that might result from improvements in airfield and terminal-area operations. This study was conducted for the Federal Aviation Administration (FAA) Office of Systems Studies and Cooperative Programs (ADL-5) to help the FAA and industry better understand the expectations and limitations of airport capacity increases achievable through technical solutions. The focus of this study is not on how new technology results in operational improvements, but rather on how much of an operational improvement is necessary to increase capacity.

An analysis of the key operational parameters in today's airfield operations yields the following conclusions:

1. The greatest capacity increases come from the addition of new runways that are properly placed to allow additional independent arrival and/or departure streams, both under Visual Flight Rules (VFR) and under Instrument Flight Rules (IFR). The resulting increase in capacity is from 33 to 100 percent (depending on whether the baseline is a single, dual, or triple runway configuration).

2. While most of the time weather conditions support VFR operations, IFR operations must be used some of the time, resulting in decreased capacity due to the more restrictive rules on the use of available runways. Development of multiple approach concepts to permit simultaneous instrument approaches (where not currently allowed) increases IFR capacity by 44 to 100 percent (depending on whether the baseline is a single runway, two dependent, or two independent runways), significantly reducing the difference between IFR and VFR capacity.

3. Another area for significant increases in IFR capacity is reduction in separation minima during final approach. A reduction in the diagonal separation requirement from 2 nmi to 1 nmi for dependent parallel operations would increase capacity for that configuration by 25 percent. Reduction in the longitudinal separation requirements from 3 to 2½ nmi (with a 1-nmi reduction in other wake vortex separation rules) would increase capacity by 15 percent.

4. Technical solutions that result in operational improvements--such as reduced variability in interarrival time and reduced runway

occupancy times--do not increase capacity as much as separation reductions, but still offer potential capacity increases of as much as 18 percent for VFR and 16 percent for IFR.

BACKGROUND

Growth of air traffic in the post-deregulation era has resulted in increased congestion and growing numbers of delays, prompting demands for increased airport capacity. The need for additional airport capacity could be accommodated through the construction of new airports and new runways; however, environmental and noise concerns and the lack of available land for expansion at many airports often preclude such solutions. Attention has thus turned to technical options for increasing the capacity of the existing runways.

This study of potential increases in airport capacity through Air Traffic Control (ATC) system improvements in the airport and terminal area was conducted for the FAA Office of Systems Studies and Cooperative Programs (ADL-5) to help FAA and industry better understand the expectations and limitations of airport capacity increases achievable through technical solutions. The question this study is designed to answer is "How much of a capacity increase can be expected from improved performance in the terminal area?" The question, "How can new technology improve performance?" is a separate challenge beyond the scope of this study.

Definition and Computation of Airport Capacity. As noted in the FAA Airport Capacity Enhancement Plan, "Airfield capacity is the maximum number of aircraft operations (takeoffs and/or landings) that can be processed during a specified time interval and under specific conditions at an airport when there is a continuous demand for service". Capacity is determined by a wide variety of factors, including the following:

- Airfield configuration: The number and orientation of runways; exit locations; supporting taxiways.

- ATC operational rules and procedures: The rules defining minimum allowable separations between arriving and departing aircraft on the same, intersecting, or nearby runways. These vary in accordance with whether instrument procedures and radar separations, or visual procedures and separations, are in use.

- Operating conditions: Weather conditions, such as wind and ceiling/visibility, which determine whether instrument or visual procedures may be used.

- Aircraft and controller performance: Aircraft speeds and requirements for approach and landing; the controller's ability to achieve minimum spacings between aircraft.

- Demand characteristics: Types of aircraft using the airport; whether demand is for arrivals, departures, or both and in what proportions.

- External factors: Restrictions on airport use because of noise, quotas, obstacles, etc.

Many of these factors vary from airport to airport; consequently, at a specific airport any of these factors can be the limit on capacity. Technical approaches to capacity improvement can affect only some of the factors listed above. At a given airport, the airfield configuration is fixed; the types of aircraft using the airport are defined by the operators' needs; arrival and departure peaks are determined by operating schedules; and the weather conditions are certainly not subject to control. However, introduction of new features into the ATC system, once they are demonstrated to be safe, can allow changes in ATC operational rules and procedures. Also, aircraft performance can be improved through provision of new navigation systems and avionics, and controller performance can be improved by provision of advanced controller aids.

Estimation of the magnitude of capacity increases resulting from these types of improvements is not a simple problem. Because any of the factors listed above may be the limitation on the capacity of a particular airport, a change in a particular parameter may have a major effect at one airport and no effect at another. It may even have a major effect in one weather condition (e.g., visual conditions) but none in another (instrument conditions). A generalization of capacity increases from technical improvements must take into account the variety of airfield configurations, levels of demand, and weather conditions that may exist at any particular airport.

Study Approach. In this study, a set of nominal runway configurations, aircraft types, and demand characteristics are defined. Parameters that may be changed as a result of some technical improvement to the ATC system are then varied and the FAA Airfield Capacity Model is used to compute the resulting changes in airfield capacity.

Nominal conditions were defined as follows:

- Runway configurations. Three runway configurations were selected as being representative of the types of runway configurations that exist at most major airports: (1) single runway; (2) parallel runways spaced 700 to 2499 feet (referred to as "duals"); and 3) parallel runways spaced 2500 to 4299 feet. These runway configurations have different restrictions on their operation due to aircraft separation and wake vortex considerations. Converging and intersecting runways were not included, since results would be similar to the dual and parallel cases.

- Demand Characteristics. Capacity was computed for three arrival-departure proportions: (1) arrivals-only; (2) mixed operations (50 percent arrivals, 50 percent departures); and (3) departures-only. A fleet mix typical of most major airports was selected consisting of 15 percent small aircraft (e.g., Swearingen SW-4 ("Metro")); 20 percent large prop (e.g., Convair 580); 55 percent large jet (e.g., Boeing 727); and 10 percent heavy jets (e.g., Lockheed L-1011).

- Weather Conditions. The weather conditions affect capacity by determining the operational ATC rules that apply. When the conditions support their use, visual procedures are used since they are the most efficient. When weather conditions do not support visual operations, instrument procedures and radar separations must be used. The transition from VFR to IFR is not an instantaneous transformation at a particular ceiling and visibility; rather, as the ceiling and visibility gets lower, radar separations must be provided along a longer segment of the final approach, and at certain ceilings and/or visibilities, certain runway operations become unavailable.

  This study considers two conditions: (1) capacity under visual conditions, and (2) capacity under instrument conditions. Weather conditions assumed are, for VFR, visibility sufficient to allow visual approaches and visual separations along the entire final approach (5 nmi and 5000 feet were used in the model) and, for IFR, visibility low enough to require Instrument Landing System (ILS) approaches, radar separations, and related IFR separation rules (0 nmi and 0 feet were used in the model).

Parameters that were identified as being susceptible to change through technical improvements to the ATC system are:

- Interarrival separation minimums (both longitudinal and, in IFR, diagonal)
- Interdeparture separation minimums
- Variability in Interarrival Time (IAT)
- Arrival Runway Occupancy Time (ROT) mean and variation
- Departure ROT mean and variation
- Length of common final approach

In the analysis that follows, today's capacity is described. Individual parameter values are then reduced and the percent change in airfield capacity observed. Upper bounds on capacity increases are also computed; these upper bounds fit two scenarios: (1) an "unrealistic" theoretical upper bound on capacity computed by setting parameters to their absolute minimums, and (2) a "realistic" upper bound computed by setting parameters halfway between the baseline (today) and the unrealistic upper bound values. Conclusions are drawn for both IFR and VFR. A comparison of potential capacity increases in IFR and VFR is also provided.

CAPACITY INCREASES UNDER VISUAL FLIGHT RULES

Today's VFR capacity. Today's VFR operations are characterized by pilot-maintained visual separations on final approach. Operation of virtually all multiple runway configurations is allowable (subject to the external factors pointed out previously), with separation between multiple arrival and departures streams maintained visually. Wake vortices are a factor for aircraft on the same or closely-spaced parallel ($\leq$2500 ft) paths; however, the effect on capacity of the additional separation requirements, to protect against vortex encounters, is small.

The capacities of the nominal runway configurations under these operations are shown in Figure ES-1. As shown in Figure ES-1a, the capacity of a single runway, per hour, is either 36.6 arrivals; or 57.9 departures; or, at 50 percent arrivals, 29.9 arrivals and 29.9 departures. (These values should be treated as rates, and can thus have a fractional component.) Likewise, dual runways (Figure ES-1b) can accommodate 70.6 arrivals (35.3 to each runway); or 111.9 departures (56 from each runway); or 56.7 arrivals and 56.7 departures (28.4 arrivals and 28.4 departures on each of the two runways). Note that the capacity of dual runways is slightly less than double that of a single runway; wake vortex considerations require that an aircraft be separated not only from the one preceding it on the same approach, but also the one on the adjacent approach, with a resulting loss of capacity (albeit only one aircraft per hour). Once runways are separated by more than 2500 feet (Figure ES-1c), they become wake-vortex independent and capacity for any proportion of arrivals and departures is double that of a single runway.

These capacity values represent the baseline ("today's") capacity. Actual capacities at airports may differ from these values because of differences in fleet mix, ROTs, and other factors. Percentage increases in capacity from reductions in parameter values shown in the following sections represent increases above these baseline values.

Effect of Reductions in Individual Parameters. To gain some insight into the most effective means for increasing capacity for a particular runway configuration/demand condition, the values of the parameters were reduced individually by a nominal amount. The basis for reductions is as follows: parameters representing variabilities, such as IAT variability, were

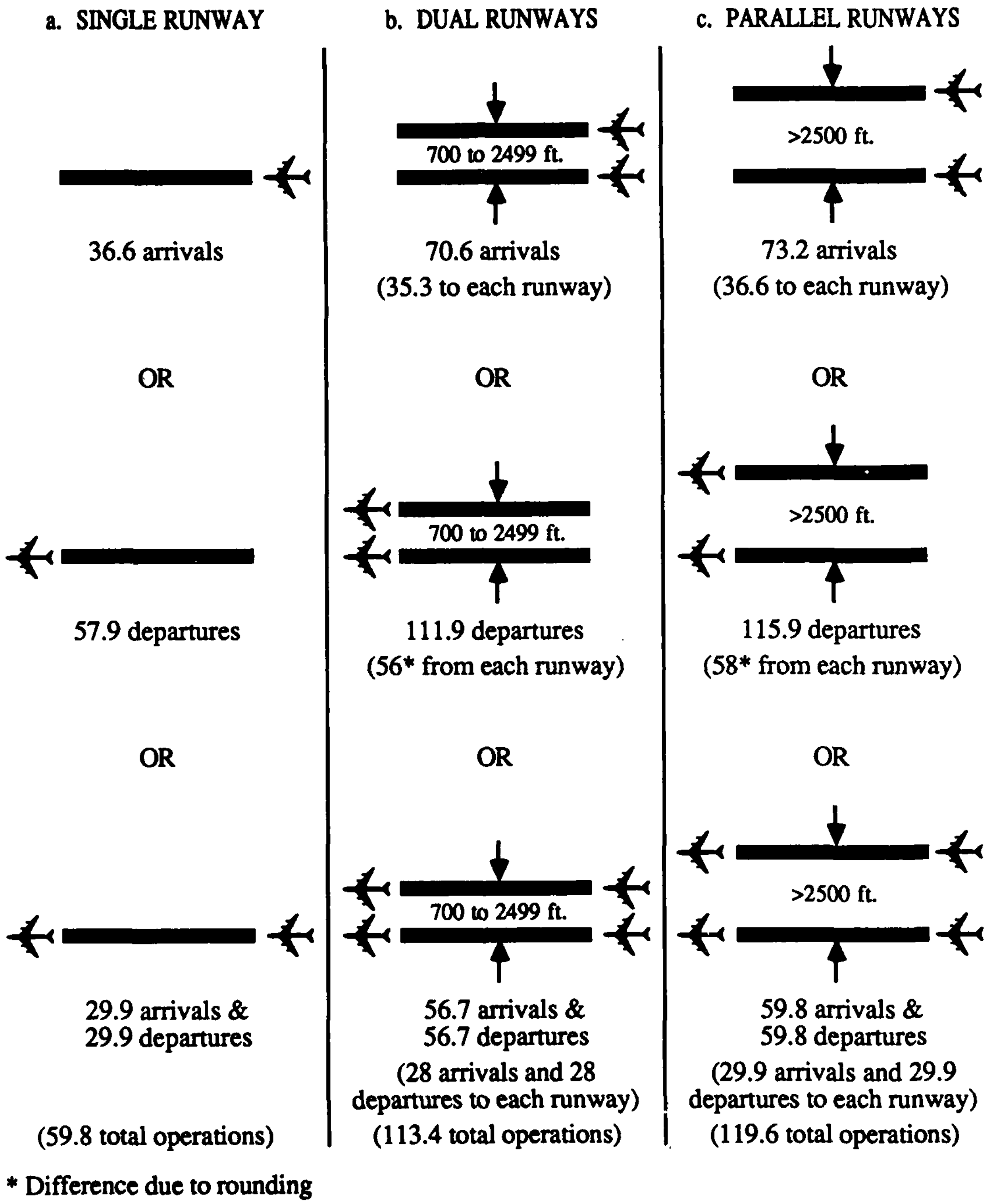


FIGURE ES-1
TODAY'S VFR CAPACITY

reduced by 50 percent. For parameters representing means or minimums, such as interarrival separations or mean departure ROT, an arbitrary "lowest achievable" value was identified, and then the parameter reduced by 50 percent of the difference between the baseline and this "lowest achievable" value.

The effect of reductions in the parameters to these values is illustrated in Figure ES-2, which shows the percentage increase in capacity for arrivals-only, 50 percent arrivals, and departures-only operations from reductions in parameter values (individually). As an example, if IAT variability were reduced from 18 seconds to 9 seconds (1 standard deviation (s.d.)), then VFR arrivals-only capacity would increase 17-18 percent (depending on runway configuration).

As shown in Figure ES-2a, the factors that limit arrivals-only capacity today are those that control average separation between aircraft on final approach--IAT variability, interarrival separations, and any extra separation that occurs along the common final approach due to speed differences. Arrival ROT is not a factor at the assumed baseline shown in the table. However, ROTs vary from airport to airport (and even from runway to runway). The baseline chosen represents the lower ROTs observed today; at airports with higher ROTs, capacity is lower. For example, ROTs 5 seconds higher than the baseline values result in 4 percent less capacity; 10 seconds higher, 8 percent less capacity. Consequently, there is a motivation for reducing ROT to the baseline values at those airports that currently have higher ROTs.

For VFR mixed operations at 50 percent arrivals (Figure ES-2b), the story is quite different. When arrivals and departures must use the same runway, then ROT becomes the most significant factor. Reductions in mean arrival ROT, mean departure ROT, and variability in departure ROT provide the largest gains in capacity. Reductions in departure separations also provide an increase in capacity. Reductions in those factors that determine actual separations on final approach--minimum separations, IAT variability, and length of common final--produce a negligible or no capacity gain.

Note that reductions in some of the key variability parameters, such as IAT variability and variability in arrival ROT, produce only negligible capacity gains for VFR mixed operations. Rather than representing unused capacity, this variability is used to advantage by a controller. Given today's mean arrival and departure ROT, a controller can request an average interarrival separation such that, on average, one departure can be released between each arrival pair. The process is variable, however. If the arrival separation is below average and the ROT above average, no departure may be released. If the arrival separation is above average and the ROT below, then multiple departures may be released. The net result is still one departure for every arrival. If IAT and arrival ROT

a. ARRIVALS - ONLY

Parameter	Reduction From	Reduction To	Percentage Increase In VFR Capacity
IAT variability	18 s	9 s	17-18%
Interarrival separations (observed)	1.9 - 4.5 nmi	1.7 - 4.0 nmi	7%
Common final	3-5 nmi	2-3 nmi	2-3%
Arrival ROT mean	40-50 s	30-40 s	0%
Arrival ROT variability	10 s	5 s	0%

b. 50% ARRIVALS, 50% DEPARTURES

Parameter	Reduction From	Reduction To	Percentage Increase In VFR Capacity
Arrival ROT mean	40-50 s	30-40 s	8-9%
Departure ROT mean	35-40 s	25-30 s	4%
Departure ROT variability	6 s	4 s	3%
Departure separations	50-60 s (120 s / heavies)	40-50 s (100 s / heavies)	3%
IAT variability	18 s	9 s	<1%
Arrival ROT variability	10 s	5 s	<1%
Interarrival separations	1.9-4.5 nmi	1.7-4.0 nmi	0%
Common final	3-5 nmi	2-3 nmi	0%

c. DEPARTURES - ONLY

Parameter	Reduction From	Reduction To	Percentage Increase In VFR Capacity
Departure separations	50-60 s (120 s / heavies)	40-50 s (100 s / heavies)	18%
Departure ROT mean	35-40 s	25-30 s	0%
Departure ROT variability	6 s	4s	0%

FIGURE ES-2
INCREASES IN VFR CAPACITY FROM PARAMETER REDUCTIONS

variability were reduced to 0.0, a controller could guarantee that one departure be released between each pair of arrivals; however, the total number of operations would not increase.

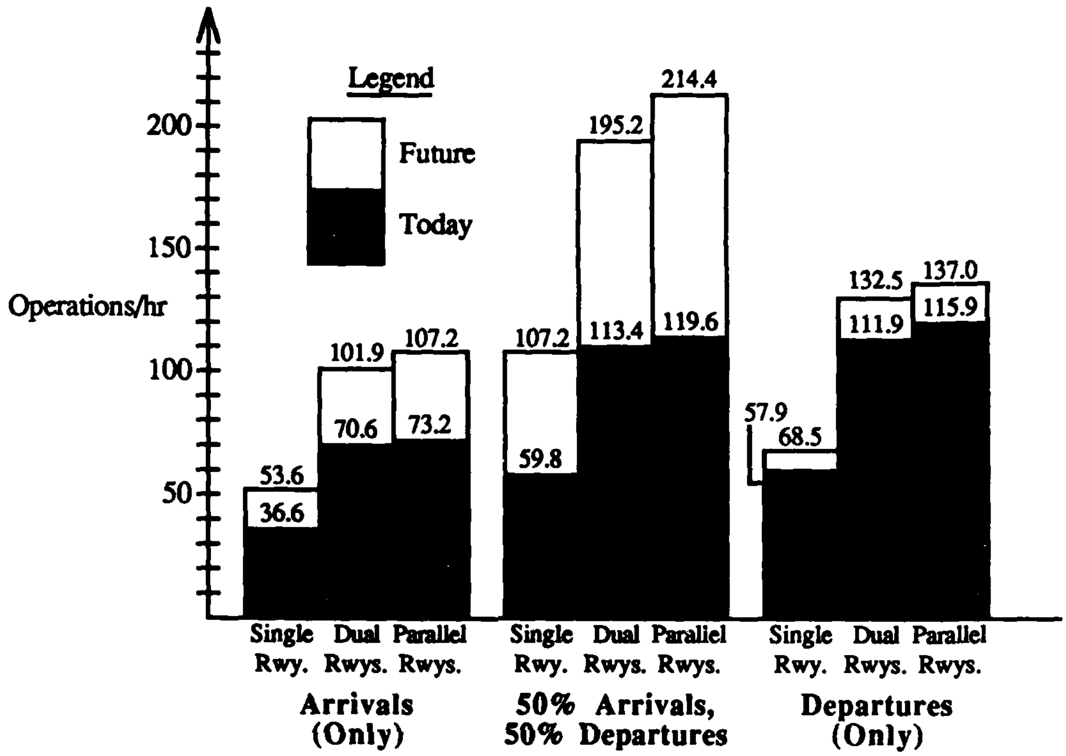
Finally, for VFR departure-only operations (Figure ES-2c), only two parameters are relevant: departure separations and departure ROT. A relatively small decrease in departure separations (from 60 seconds to 50 seconds) produces a significant gain (18 percent) in departure capacity. Departure ROT is not a factor; there is no increase in departure-only capacity from reduced departure ROT unless departure separation rules are reduced substantially.

Bounds on Capacity Increases. The capacity increases shown in the previous section reflect the effects of changing one parameter at a time. It is reasonable to expect that many or all of these parameters may be changed in the future. To provide a better understanding of the limitations on potential capacity increases that may be provided through technical solutions, and to set realistic expectations for the amount of future increases, upper limits on capacity increases were computed. These upper limits take two forms: (1) A purely theoretical upper bound that is useful for comparison only, based on reductions in the parameter values to absolute minimums (0.0 for variability parameters, the "lowest feasible" values for parameters representing means or minimums); and (2) A more "realistic" upper bound meant to represent an upper limit on expected future increases, based on reductions that are only half of those that produce the theoretical upper bounds.

The theoretical upper bound on VFR capacity increases is shown in Figure ES-3. Also listed in the figure are the parameter values that produce these capacity increases. The upper limit for arrival-only increases is 44-46 percent; for departures, 18 percent. Only limited increases would be possible for mixed operations unless ROT is decreased; therefore, the mixed operations capacity increases shown assume that ROT is reduced to 15-25 seconds. The upper bound for increases in mixed operations capacity under this assumption is 72-79 percent.

The "realistic" upper bound on capacity increases is shown in Figure ES-4. The parameter value reductions these increases are based upon are also listed in the figure. Small decreases (5 seconds) in mean arrival and departure ROT are included in this scenario. Capacity increases are 20 percent for arrival-only operations; 22 percent for mixed operations; and 18 percent for departure-only operations.

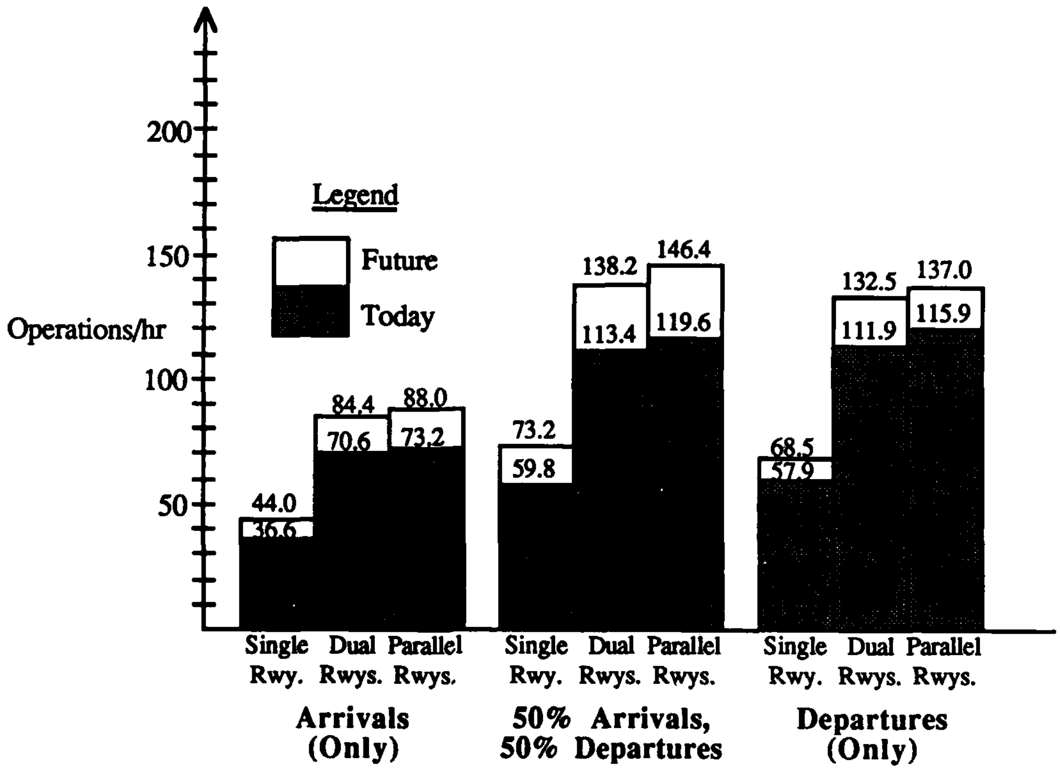
It should be noted that the capacity increases shown in these two scenarios reflect the general increases in capacity that can be expected through changes in the parameters to the levels indicated. Actual changes at specific sites will vary due to local conditions and any external factors that may apply at that particular airport.



Assumed Basis for Capacity Increases

Parameter	Reduction From	To
Arrival separations	no change	
Departure separations	35-60 s (120 s for heavies)	25-40 s (80 s for heavies)
IAT variability (1 s.d.)	18 s	0 s
Arrival ROT -- mean	no change	
(mixed operations(class A, B, C, D))	(40, 40, 45, 50 s)	(35, 35, 40, 45 s)
-- variability (1 s.d.)	10 s	5 s
Departure ROT -- mean	no change	
-- variability (1 s.d.)	6 s	0 s
Length of common final approach	3-5 nmi	2-3 nmi

FIGURE ES-3
THEORETICAL UPPER BOUND ON VFR CAPACITY INCREASES



Assumed Basis for Capacity Increases

Parameter	Reduction From	To
Arrival separations	no change	
Departure separations	35-60 s (120 s for heavies)	30-50 s (100 s for heavies)
IAT variability (1 s.d.)	18 s	9 s
Arrival ROT -- mean (class A, B, C, D)	40, 40, 45, 50 s	35, 35, 40, 45 s
-- variability (1 s.d.)	10 s	5 s
Departure ROT -- mean	35-40 s	30-35s
-- variability (1 s.d.)	6 s	4 s
Length of common final approach	3-5 nmi	2-3 nmi

FIGURE ES-4
"REALISTIC" UPPER BOUND ON VFR CAPACITY INCREASES

Conclusions for VFR. Based on this analysis, the following conclusions may be drawn for VFR capacity:

1. There is potential for VFR capacity increases through ATC system improvements. A realistic estimate of the capacity increases from these types of improvements is approximately 18-22 percent, depending on whether the operation is arrivals-only, mixed, or departures-only.

2. Most of the potential gain, for arrivals, comes from reduced interarrival time variability (17-18 percent).

3. All of the increase in departures-only capacity comes from decreasing departure separation requirements, allowing a reduction in the average time between release of successive departures.

4. Capacity increases for mixed operations (50 percent arrivals) are limited unless there are reductions in runway occupancy time (either arrival, departure, or both).

CAPACITY UNDER INSTRUMENT FLIGHT RULES

Today's IFR Capacity. Today's IFR operations are characterized by controller-maintained radar separations on final approach and significant restrictions on the use of multiple runway configurations for the purpose of ensuring aircraft separation (for both wake-vortex and collision avoidance). The result of these restrictions is a substantial reduction in the capacity of most runway configurations compared with VFR.

The IFR capacity of the three runway configurations analyzed in this study is shown in Figure ES-5. The IFR capacity of a single runway (Figure ES-5a) is 26.6 arrivals; or 54.8 departures; or, at 50 percent arrivals, 26.6 arrivals and 26.6 departures. More than 26.6 departures could be accommodated without reducing the 26.6 arrivals. The capacity of dual runways (Figure ES-5b) is the same as that of a single runway, since under IFR only single arrival and departure streams may be operated to parallel runways with spacing of less than 2500 feet. Once spacing increases above 2500 feet, dependent parallel operations may be conducted (Figure ES-5c). This allows 36.9 arrivals; or 109.6 departures (departures may be operated independently); or 36.9 arrivals and 36.9 departures. Again, more than 36.9 departures may be operated without a reduction in the number of arrivals. At 4300 feet spacing and above, the runways may be operated independently and capacity is a multiple of the single runway capacity.

These capacity values represent the baseline ("today's") IFR capacity. Actual capacities of airports may be different than these values because of local conditions, such as differences in fleet mixes and ROTs.

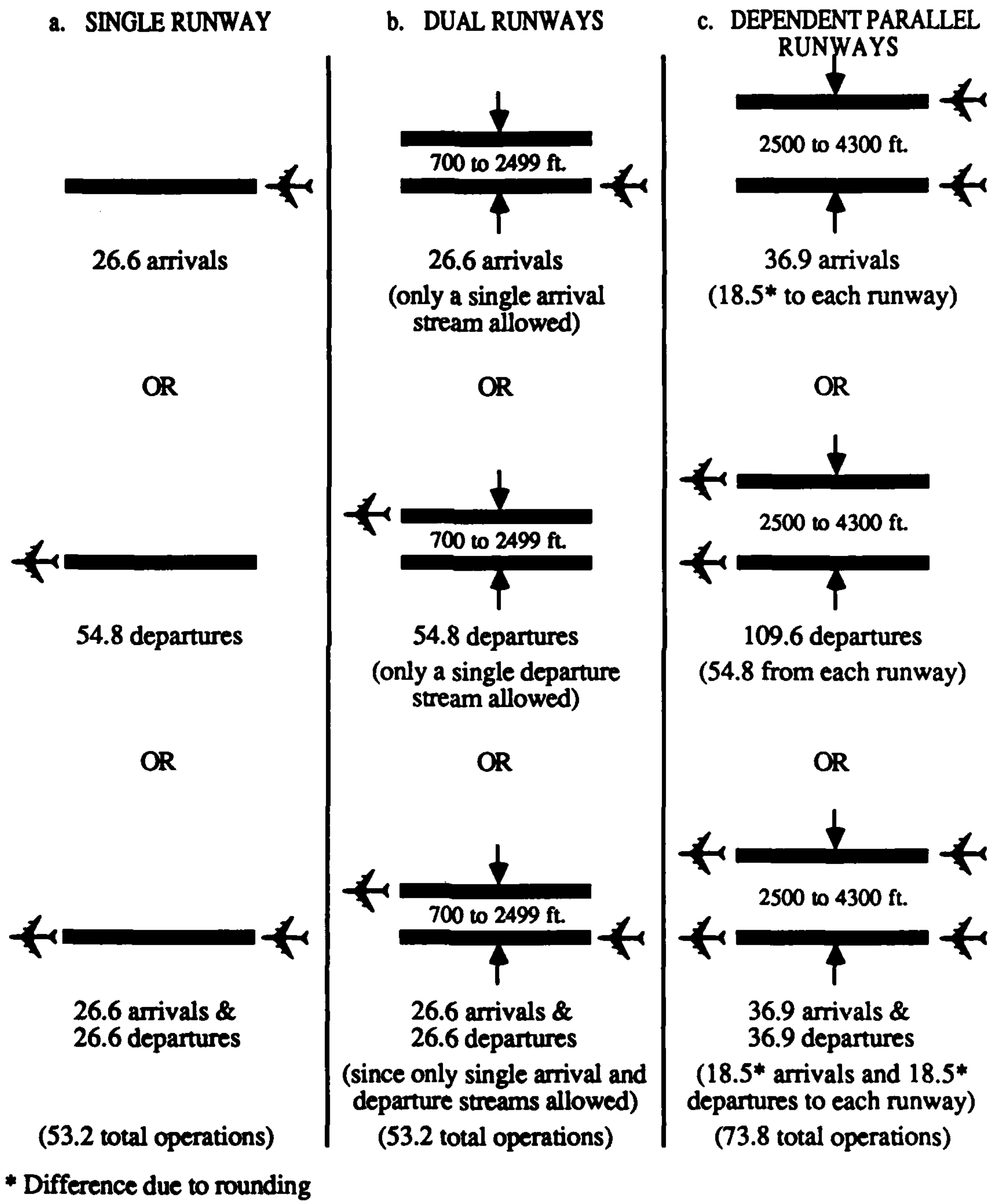


FIGURE ES-5
TODAY'S IFR CAPACITY

Percentage increases in capacity from reductions in parameter values, shown in the following section, represent increases above these baseline values.

Effect on IFR Capacity of Variation in Individual Parameters. As was done for VFR, the parameter values were reduced individually to find those parameters that offer the most potential to increase IFR capacity. The basis for reduction is similar to that used in the VFR analysis: parameters representing variabilities were reduced 50 percent, and parameters representing means or minimums were reduced by 50 percent of the difference between the baseline (today's) values and a "lowest feasible" value. Figure ES-6a shows the percentage increases in capacity that result from reductions in the parameters to these values (individually). For example, a reduction in IAT variability from 18 seconds to 9 seconds (1 s.d.) results in an increase in IFR arrivals-only capacity of 12-16 percent, depending on runway configuration.

The factors with the greatest impact on arrivals-only capacity under IFR, as shown in Figure ES-6(a), are separation requirements on final approach--the diagonal requirement for dependent parallels, the longitudinal requirements for single and dual configurations--and IAT variability. Together, they represent a significant potential gain in capacity of 30 to 40 percent, depending on runway configuration. The length of common final approach has only a small impact; and ROT has none at all, since arrival separations, in terms of time, are much larger than ROT.

An additional area for IFR arrival capacity increases is the development of multiple approach concepts. One of the major differences between VFR and IFR operations is the restrictions on the use of multiple runway configurations; technical solutions that would allow use of multiple runway configurations in IFR offer the potential for substantial increases in IFR capacity. These capacity increases range from 44 percent, by allowing independent operations where only dependent operations are currently allowed, to 100 percent, by allowing, for example, converging operations where only a single runway is currently available.

For mixed operations with 50 percent arrivals (Figure ES-6b), the effect of reductions in parameters is similar. Changes in arrival separations (both longitudinal and diagonal), IAT variabiiity, and length of the common final approach path produce the same percentage increases as for arrivals-only operations, except for single runways, where percentage increases from changes in any of these factors is limited to 3-4 percent because of limitations imposed by arrival ROT. A 10-second reduction in arrival ROT would remove these limitations, allowing the same percentage increases for single runways as for dual runways, where ROT is not a factor. Single runway operations at 50 percent arrivals is the only IFR operation where ROT limits capacity increases.

a. ARRIVALS - ONLY

Parameter		Reduction From	Reduction To	Percentage Increase In IFR Capacity
Interarrival separations	Diag.[1]	2 nmi	1 nmi	25%
	Long.[2]	3-6 nmi	2 1/2-5 nmi	15%
IAT variability		18 s	9 s	12-16%
Common final		7 nmi	5 nmi	2-3%
Arrival ROT	mean	40-50 s	30-40 s	0%
	variability	10 s	5 s	0%

b. 50% ARRIVALS, 50% DEPARTURES

Parameter		Reduction From	Reduction To	Percentage Increase In IFR Capacity
Interarrival separations	Diag.[1]	2 nmi	1 nmi	25%
	Long.[2]	3-6 nmi	2 1/2-5 nmi	15%[3]
IAT variability		18 s	9 s	12-16%[3]
Common final		7 nmi	5 nmi	2-3%
Arrival ROT	mean	40-50 s	30-40 s	0%
	variability	10 s	5 s	0%
Departure ROT	mean	35-40 s	25-30 s	0%
	variability	6 s	4 s	0%

c. DEPARTURES - ONLY

Parameter		Reduction From	Reduction To	Percentage Increase In IFR Capacity
Departure separations		50-60 s (120 s / heavies)	40-50 s (100 s / heavies)	20%
Departure ROT	mean	35-40 s	25-30 s	0%
	variability	6 s	4 s	0%

1 For dependent parallels only.
2 For single & dual runways only.
3 Capacity increase limited to 3-4% for single runways due to ROT limitations.

FIGURE ES-6
INCREASES IN IFR CAPACITY FROM PARAMETER REDUCTIONS

To increase IFR departure capacity (Figure ES-6c), departure separation requirements (which are based on time, not distance) must be decreased. Relatively small decreases of 10 seconds (from 60 to 50 seconds) with reductions from 2 minutes to 100 seconds for heavies produce 20 percent increases in departure capacity. Departure ROT is not a limiting factor on IFR departure-only capacity increases.

Bounds on Capacity Increases. The capacity increases shown in the previous section show the effect of changing one parameter at a time; actually, many or all of these parameters may be changed in the future. The theoretical upper bound (representing the upper limit on capacity increases through technical solutions) and a "realistic" upper bound on capacity were computed for IFR. As in the VFR analysis, the theoretical upper bound on IFR capacity is based on reductions in parameter values to absolute minimums: 0.0 for variability parameters, "lowest feasible" values for means and minima. The "realistic" upper bounds represent reductions of half these amounts.

The theoretical upper bound on IFR capacity increases is shown in Figure ES-7, along with a list of the parameter values that produce these increases. Capacity increases range from 50 percent (departures-only, any configuration) to 153 percent (arrivals-only, dependent parallels). These represent unachievable increases; the more "realistic" estimate of the upper limit of increases from ATC system improvements in IFR is shown in Figure ES-8, also with the parameter values that produce these increases. These increases range from 9 to 78 percent, depending on runway configuration and percent arrivals. In contrast, note that the development of the multiple approach concepts produce achievable capacity increases ranging from 44 to 100 percent.

Conclusions for IFR. The following conclusions are drawn regarding IFR capacity:

- The following concepts provide the largest IFR capacity increases:

    1. Multiple independent approach concepts, at 44 to 100 percent increases in IFR capacity

    2. Reduction in separation requirements between approaches for multiple dependent approaches, 25 percent

    3. Reduction in longitudinal separation standards, 15 percent

    4. Reduction in system variabilities, 12-16 percent

- While reductions in separation requirements produce greater increases in capacity than reductions in variability parameters, significant capacity increases do result from decreases in the variability parameters.

- Runway occupancy time, which has a major impact in VFR, is not a significant limitation in IFR and will not interfere with the capacity gains shown above. (An exception is single runway mixed operations, where arrival ROT decreases are needed to support increases from other factors.)

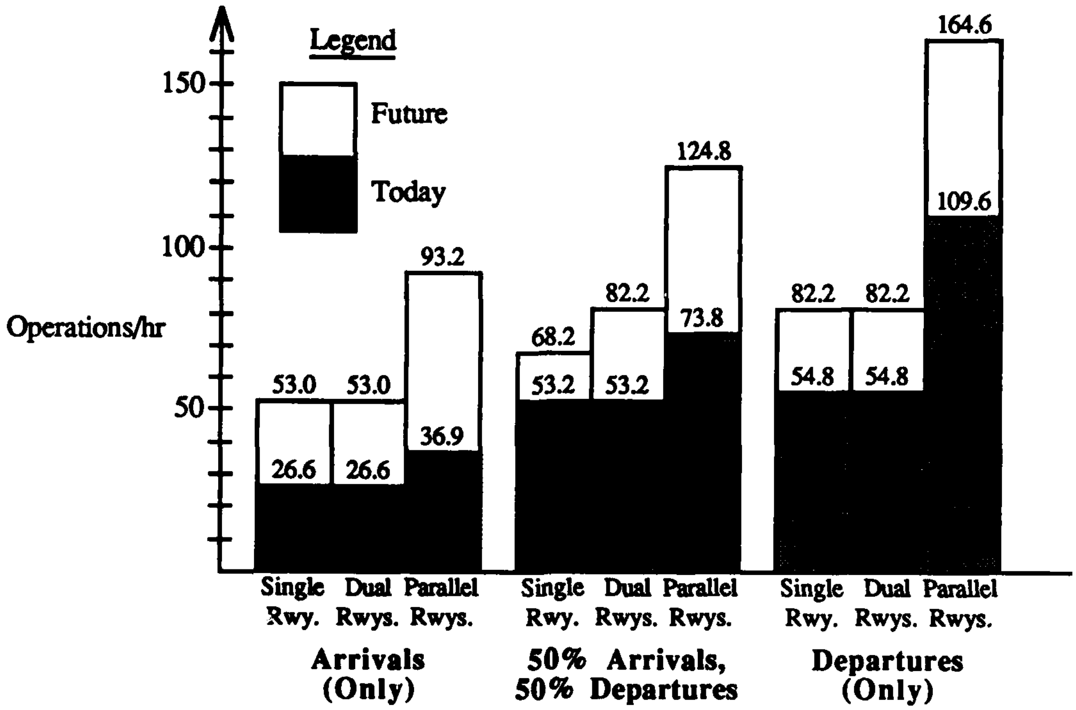
IFR VS. VFR CAPACITY

One of the areas of greatest concern regarding airfield capacity is the difference in capacity between VFR and IFR operations. Given the same runway configuration and demand conditions, the IFR capacity is invariably less than the VFR capacity. Table ES-1 shows the differences between today's VFR and IFR capacities for the runway configurations and demand conditions analyzed in this study. The IFR capacity is lower than the corresponding VFR capacity by amounts ranging from 5 to 62 percent. A substantial number of weather-related delays could be reduced if this capacity "gap" could be narrowed.

A comparison of the effects of reducing the individual parameters in VFR with their effects in IFR provides an indication of whether this "gap" can be reduced, and if so, through which parameters. A summary of the expected capacity increases from parameter reductions in VFR and in IFR is shown in Table ES-2.

One area in which differences in the effects of the parameters is evident is in reduced arrival separations. Substantial (15 to 25 percent) increases can be expected from reduced longitudinal and diagonal separations for IFR arrivals-only and mixed operations, whereas only smaller or no increases can be expected for these operations in VFR. Conversely, little improvement can be expected in the IFR/VFR gap from reduced IAT variability, length of common final, or ROT; potential capacity increases from these factors are usually as large or larger in VFR than in IFR. (For certain operations, reductions in these parameters in both VFR and IFR may increase the gap.)

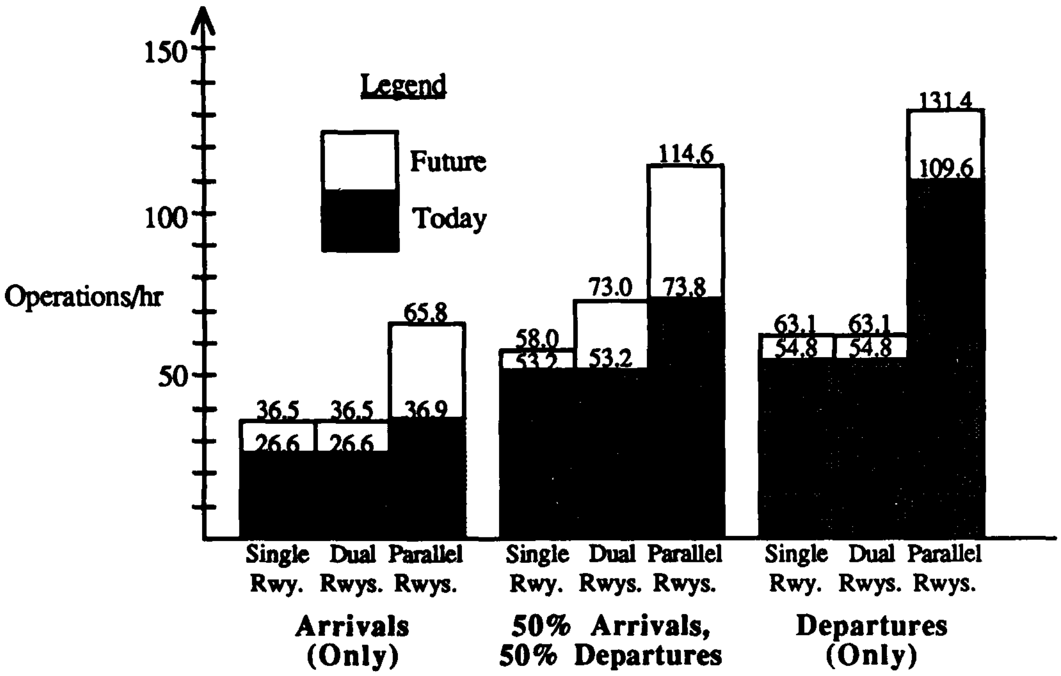
For IFR departure operations, the only parameter that can provide a capacity increase is departure separations; here, the increase in IFR is only slightly larger than that in VFR. However, for any configuration that allows the same number of departure streams in IFR that are allowed in VFR (i.e., single runway or parallel runways spaced more than 2500 feet), the difference between the IFR and VFR departures-only capacity is only 5 percent.



Assumed Basis for Capacity Increases

Parameter	Reduction From	Reduction To
Arrival separations	3, 4, 5, 6 nmi	2, 2 1/2, 3, 4 nmi
(diagonal for dependent parallels)	2 nmi	1/2 nmi
Departure separations	60 s (120 s for heavies)	40 s (80 s for heavies)
IAT variability (1 s.d.)	18 s	0 s
Arrival ROT -- mean (class A, B, C, D)	no change	
-- variability (1 s.d.)	10 s	0 s
Departure ROT -- mean	no change	
-- variability (1 s.d.)	6 s	0 s
Length of common final approach	7 nmi	3-4 nmi

FIGURE ES-7
THEORETICAL UPPER BOUND ON IFR CAPACITY INCREASES



Assumed Basis for Capacity Increases

Parameter	Reduction From	Reduction To
Arrival separations	3, 4, 5, 6 nmi	2 1/2, 3, 4, 5 nmi
(diagonal for dependent parallels)	2 nmi	1 nmi
Departure separations	60 s (120 s for heavies)	50 s (100 s for heavies)
IAT variability (1 s.d.)	18 s	9 s
Arrival ROT -- mean (class A, B, C, D)	no change	
-- variability (1 s.d.)	10 s	5 s
Departure ROT -- mean	no change	
-- variability (1 s.d.)	6 s	4 s
Length of common final approach	7 nmi	5 nmi

FIGURE ES-8
"REALISTIC" UPPER BOUND ON IFR CAPACITY INCREASES

TABLE ES-1
COMPARISON OF TODAY'S VFR AND IFR AIRFIELD CAPACITIES

RUNWAY CONFIGURATION	TYPE OF OPERATION								
	Arrivals-Only			50% Arrivals, 50% Departures			Departures-Only		
	VFR (aircraft/hr)	IFR (aircraft/hr)	Difference (percent)	VFR (aircraft/hr)	IFR (aircraft/hr)	Difference (percent)	VFR (aircraft/hr)	IFR (aircraft/hr)	Difference (percent)
Single	36.6	26.6	10.0 (-27%)	59.8	53.2	6.6 (-11%)	57.9	54.8	3.1 (- 5%)
Dual	70.6	26.6	44.0 (-62%)	113.4	53.2	60.2 (-53%)	111.9	54.8	57.1 (-51%)
Dependent Parallel	73.2	36.9	36.3 (-50%)	119.6	73.8	45.8 (-38%)	115.9	109.6	6.3 (- 5%)

TABLE ES-2
EXPECTED PERCENTAGE CAPACITY INCREASES FROM PARAMETER REDUCTIONS IN VFR AND IFR

a. FOR VFR OPERATIONS

Parameter / Type of Operation	Arrival Separations: Diagonal Separations	Arrival Separations: Longitudinal Separations	Departure Separations	Interarrival Time Variability	Common Approach Path	Arrival ROT	Departure ROT
Degree of Reduction	N/A	1.9 nmi → 1.7 nmi 2.7–4.5 → 2.4–4.0	10–20 s	18 s → 9 s	3–5 nmi → 2–3 nmi	10 s	10 s
Arrivals Only	/ / /	7%	/ / / /	17–18%	2–3%	*	/ / /
50% Arrivals, 50% Departure	/ / /	**	3%	**	**	8–9%	4%
Departures Only	/ / /	/ / / /	18%	/ / / /	/ / / /	/ / /	*

b. FOR IFR OPERATIONS

Parameter / Type of Operation	Arrival Separations: Diagonal (Dependent Parallel)	Arrival Separations: Longitudinal (Single, Dual Rwys)	Departure Separations	Interarrival Time Variability	Common Approach Path	Arrival ROT	Departure ROT
Degree of Reduction	2 nmi → 1 nmi	3 nmi → 2.5 nmi 4–6 nmi → 3–5 nmi	10–20 s	18 s → 9 s	7 nmi → 5 nmi	10 s	10 s
Arrivals Only	25%	15%	/ / / /	12–16%	2–3%	*	/ / /
50% Arrivals, 50% Departure	25%	15%***	*	12–16%***	2–3%	*	*
Departures Only	/ / / /	/ / / /	20%	/ / / /	/ / / /	/ / /	*

*No measurable impact under assumed baseline.
**No measurable impact without ROT reductions.
***Requires 10-second reduction in arrival ROT for single runway operation.

Thus, the best area to achieve a reduction in the difference between IFR and VFR capacity is through reductions in separation rules on approach or through development of multiple approach concepts that allow the same number of runways to be operated in IFR that are allowed in VFR.

CONCLUSIONS

This study focuses on the capacity increases that can result from technical improvements to the ATC system, using the existing runways. Realistic upper limits on such increases are from 15 to 26 percent in VFR (depending on runway configuration and percent arrivals), and from 9 to 78 percent in IFR. In comparison, the addition of a new runway that allows an additional independent arrival and/or departure stream results in a 33 to 100 percent capacity increase (depending on whether the baseline is a single, dual, or triple runway configuration). In VFR, this would require the construction of a new runway; in IFR, the increase could also come through development of multiple approach concepts, which can result in a 44 to 100 percent increase in IFR capacity (depending upon whether the baseline is a single runway, two dependent, or two independent runways). The greatest capacity increases thus come from the addition of a new runway, properly spaced to allow an additional independent arrival and/or departure stream.

While the capacity increase from technical ATC system improvements are not as large as those from the addition of new runways, they still represent a significant capacity gain. In addition, technical ATC system improvements that would allow operation of multiple independent IFR approach streams that are currently prohibited or operated only at very high weather minimums--such as converging and triple IFR approaches--would result in a significant decrease in the difference between the IFR and VFR capacities of particular runway configurations. The parameters that technical solutions must improve to provide the greatest increases in capacity vary as a function of percent arrivals, runway configuration, and weather conditions (VFR and IFR).

VFR Capacity. VFR operations today are characterized by pilot-maintained visual separations; it is not clear whether these can be reduced significantly over the long term. There are, however, limitations in the ability of the controllers and pilots to achieve these levels consistently. In addition, runway occupancy time is a limitation, especially where arrivals and departures use the same runway(s). There is, therefore, room to achieve some increases in VFR capacity through technical solutions that affect these factors. The parameters that have the greatest effect and the magnitude of the expected increases from reducing those parameters are:

1. Arrivals-only capacity, 17-18 percent by reducing interarrival time variability by 50 percent.

2. Departures-only capacity, 18 percent by reducing departure separations 14 to 20 percent.

3. Mixed operations, 8-9 percent by reducing mean arrival ROT 11 to 17 percent.

<u>IFR Capacity</u>. IFR operations, as distinguished from VFR, are characterized by relatively large controller-maintained radar separations and procedures for avoiding collisions and wake vortices. Not only are there significantly larger separations under IFR for individual arrival streams, but also restrictions on the use of multiple arrival streams. Consequently, the biggest impacts on IFR capacity will be from increasing the ability to operate multiple arrival streams.

The technical solutions that provide the greatest impact on IFR capacity are as follows:

1. Multiple independent approach concepts, where applicable, which can increase capacity 44 to 100 percent depending on the previous "best" capacity.

2. Reductions in the separation requirements between multiple dependent approaches, which can increase capacity by 25 percent.

3. Reductions in the longitudinal separation standards, which can increase capacity 15 percent.

4. Reduction in system variabilities, which can increase capacity by 12-16 percent.

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1.0 INTRODUCTION

This report presents estimates of the magnitude of potential increases in airfield capacity that may result from technical improvements in airfield and terminal-area operations.

1.1 Motivation for a Study of Airport Capacity

The subject of airport capacity has become predominant in recent years. The growth of air traffic in the post-deregulation era and the adoption of "hub-and-spoke" systems, which concentrate large banks of flights in relatively short time periods, has resulted in increased congestion and growing numbers of delays. This has prompted demands for increased airport capacity. This additional increase in capacity could come from construction of new runways; however, external factors, such as noise or environmental concerns or the existence of obstacles on the approach course, often prevent new construction. Because of this, technical solutions are sought as a means to increase airport capacity using the existing runways. The Federal Aviation Administration (FAA) has a number of on-going and planned projects, documented in the Airport Capacity Enhancement Plan (Reference 1), that are expected to increase airport capacity. To help FAA and industry better understand the expectations and limitations of airport capacity increases through these types of technical solutions, this study of potential capacity increases was conducted under the sponsorship of the FAA Office of Systems Studies and Cooperative Programs (ADL-5). It is designed to answer two key questions:

- How much of a capacity increase is possible? Technical improvements in airfield and terminal-area operations result in capacity increases by allowing reductions in separation rules or by reduced variability in aircraft and/or controller performance within the system. These reductions are not unlimited (variability cannot be reduced below 0, for example); consequently, it is possible to estimate the limits on capacity increases.

- In what areas are capacity increases the largest? If the capacity benefits of efforts to reduce separation standards, Runway Occupancy Time (ROT), or the variability in spacing on final approach are quantified, a comparison of projects designed to effect these changes can be made.

Answers to these questions would enable the FAA to identify needed projects and prioritize them on the basis of their capacity benefit.

1.2 Scope of this Study

Estimating potential increases in airfield capacity resulting from improved airport and terminal-area operations is a two-step process, as illustrated in Figure 1-1. New features, such as the Microwave Landing System (MLS), can result in improvements in operations. The nature and amount of improvements will be reflected in changes in the performance measures, such as ROT and Interarrival Time (IAT) variability, that determine airfield capacity. The amount of reductions in these parameters determines the increase in airfield capacity.

The focus of this study is on the second step in this process. The key measures of terminal-area operations that affect airfield capacity are well-known. One can thus hypothesize changes in these parameters and compute the resulting capacity increases independently of the feature/ technology that produces the change. The analysis can then be used in several ways:

1. To estimate capacity increases resulting from improved Air Traffic Control (ATC) system performance. As new systems are proposed and their effects on the ATC system estimated, then their capacity benefit can be calculated.

2. To estimate total expected capacity increases. By computing capacity increases based on the limits of possible changes in the parameters, an overall estimate of capacity increases can be made. This estimate can be compared against projected demands to forecast future needs for runways.

3. To identify areas where further efforts are needed. By focusing on the parameters rather than on specific projects, it is possible to identify significant areas where additional activities may be necessary to increase capacity.

However, one must be careful when using the estimates of gains in this fashion. Increases in capacity from different projects that affect the same parameter are not necessarily additive. Also, care must be taken when interpreting the capacity gains, since increases shown are from the assumed baseline case; changes that occur in the system may create a new baseline, which would change the magnitude of the expected increase.

1.3 Study Approach

To compute increases in airfield capacity, first a baseline, representing today's capacity, is established. This baseline must reflect the wide variety of airfield configurations and operating conditions that exist today. Consequently, the analysis contained in this report is rather complex; airfield capacities are computed for several runway configurations, each under several different levels of demand. The baseline conditions are described in detail in Section 2.

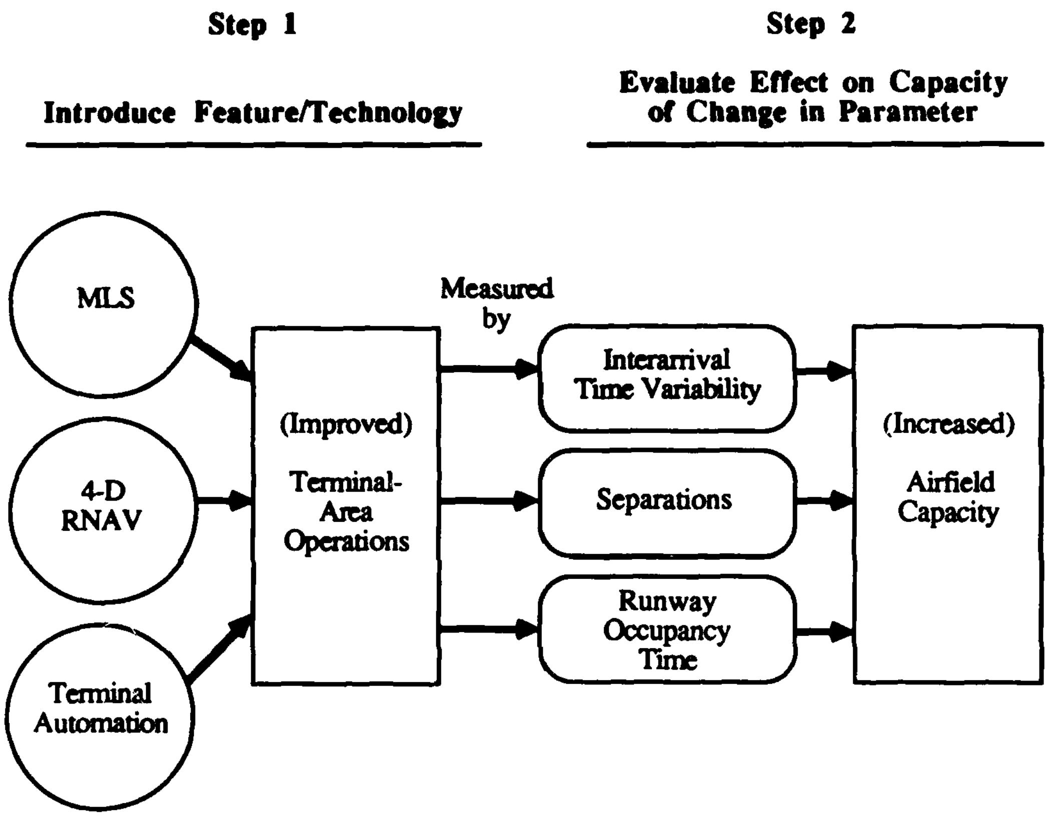


FIGURE 1-1
THE PROCESS OF COMPUTING CHANGES IN AIRFIELD CAPACITY

Once the nominal conditions are defined, parameters are identified that are susceptible to change through technical improvements in airfield and terminal-area operations. The baseline values of these parameters are defined and today's capacity is computed.

To gain some insight into the most effective means for increasing capacity, the parameters were varied individually and the airfield capacity recomputed. To obtain an understanding of the limitations on capacity increases, upper bounds on capacity increases were computed by varying all the parameters simultaneously. These variations were made to fit two scenarios: (1) an "unrealistic" theoretical upper bound on capacity increases, useful only for comparison; and (2) a more "realistic" upper bound on capacity increases, to set expectations for future capacity increases.

Based on the results of these computations, conclusions are then drawn for Visual Flight Rules (VFR) and Instrument Flight Rules (IFR) capacity. Since the difference between VFR and IFR capacity is also of concern, a comparison between VFR and IFR capacity is provided and an estimate made of the prospects of closing the "gap".

1.4 Contents of This Report

This report contains the following sections:

- Section 2: Definition and Computation of Airfield Capacity. Section 2 explains the factors that determine airfield capacity, reviews the modeling process (including a brief discussion of the FAA's Airfield Capacity Model), and defines the input parameters. Baseline conditions and assumptions are also discussed.

- Sections 3 and 4: Capacity Under Visual and Instrument Flight Rules. These sections include a discussion of today's capacity; the effect of varying individual parameters; and the results of the computation of the upper bounds. Also included are principal conclusions for VFR capacity, covered in Section 3, and IFR capacity, covered in Section 4.

- Section 5: Comparison of VFR and IFR Capacity. This section discusses the amounts and causes of the difference between VFR and IFR capacity, and analyzes the prospects for reducing the difference.

- Section 6: Summary and Conclusions. This section re-emphasizes the key conclusions for VFR and IFR capacity, and also includes a comparison of VFR and IFR capacity.

2.0 AIRPORT CAPACITY: DEFINITION AND COMPUTATION

Airfield capacity depends on a wide variety of factors, including the airfield configuration, ATC operational rules (use of which is determined by the weather conditions), and the characteristics of demand for use of a runway. This section discusses these variables and the process of computing capacity. It is not worthwhile to examine all runway configurations under all operational conditions; this study instead looks at several of the most common runway configurations under IFR and VFR. A set of baseline conditions is defined and the variables to be analyzed are identified.

2.1 Definition of Airfield Capacity

As noted in the FAA's Airport Capacity Enhancement Plan: "Airfield capacity is the maximum number of aircraft operations (either a takeoff or a landing) that can be processed during a specified interval of time and under specific conditions at an airport when there is a continuous demand for service". As such, it is actually a set of numbers, one for each particular set of conditions and type of demand that may exist at any particular airport. A comprehensive analysis of capacity must produce a matrix of values, as a function of the airfield configuration, nature of demand (whether it is arrivals or departures that need to be accommodated), and weather conditions.

The capacity of any particular combination of these factors is, in turn, governed by ATC rules and aircraft and controller performance within the system. The ATC rules define the minimum separation requirements between arriving and/or departing aircraft on the same, intersecting, or nearby runways. These rules vary as a function of the weather conditions, which determine whether instrument procedures and radar separations, or visual procedures and visual separations may be used. Aircraft performance characteristics include aircraft speeds on final approach, requirements for approach and landing, and braking characteristics. Controller performance is reflected in the variation in actual spacing between aircraft.

In addition, there are factors external to the operation of the system that may have an impact on the capacity of an airport. These factors include restrictions on the use of particular runways because of noise considerations, the existence of obstacles along the approach path, or airspace limitations. A more detailed description of the many factors that impact airfield capacity can be found in Reference 2.

Because airfield capacity depends on such a wide variety of factors, the computation of increases in airfield capacity is complex. The impact of changes in particular parameters will vary from airport to airport because of conditions particular to that airport. In spite of these limitations, it is possible to provide some general indications of the magnitude of capacity increases from technical solutions to airport and terminal-area operations.

2.2 Computation of Airport Capacity

Computation of airfield capacity involves determining the maximum rate at which arriving and/or departing aircraft can be processed to or from the available runways under the weather conditions specified. This rate, multiplied by the time unit of interest (usually 1 hour), is the capacity.

2.2.1 The Computation Process

The rate that aircraft can be processed to a particular runway configuration is determined by those factors--ATC rules or aircraft or controller performance--that are the limits for that particular runway configuration, demand, and weather conditions. The process is best illustrated by an example: an IFR arrivals-only operation to a single runway. At minimum interarrival separations plus the additional spacing required to avoid violation of these minimums, the average time between aircraft crossing the threshold will be larger than the runway occupancy time of the preceding aircraft. This minimum achievable spacing determines the capacity. Should minimum arrival separations be reduced, achievable times between aircraft crossing the threshold could become lower than arrival ROT; further increases in capacity would not be possible unless arrival ROT were reduced.

The process for computing capacity for other configurations and demand conditions is similar; different factors may be the limit on capacity in each case. To help in analysis of the complex interrelationship of these factors for the many runway configurations and conditions existing today, the FAA developed an airfield capacity model (Reference 3). This model accepts as inputs the parameters describing the critical factors in airfield capacity--required minimum separations, runway occupancy mean and variability, and other factors--and computes airfield capacity for the runway configuration, weather conditions, and demand specified. This model was used to compute the increases in airfield capacity.

2.2.2 Input Parameters

The input parameters fall into four categories: airfield descriptors, ATC rules, aircraft/controller performance parameters, and demand characteristics.

- Airfield Descriptors. These include the basic runway configurations (single, parallel, converging, and intersecting runways) and the supplementary information needed to analyze them: angles of convergence, distances from runway threshold to intersection, distance between parallel runways, etc. Exit locations are not included; while they are a primary determinant of runway occupancy times, the effect of exit locations should be reflected in the runway occupancy inputs.

- ATC Rules. These are the applicable rules from the FAA's ATC Handbook (Reference 4). They include the IFR longitudinal separation rules (3, 4, 5, 6 nautical miles (nmi)); the requirement, in IFR, for 2 nmi diagonal spacing for runways spaced from 2500 to less than 4300 feet apart; requirements for separation at runway intersections; and other ATC rules. (The user need not input all these rules; the model has defaults for use under specific weather conditions.)

- Performance Parameters. These are measured parameters of aircraft and controller performance within the system. They include such parameters as arrival and departure runway occupancy times (mean and variance); aircraft airspeeds; variation in aircraft interarrival times; length of final approach path; and others.

- Demand Characteristics. These include the types of aircraft using the runway(s) and proportion of arrivals to departures.

2.3 Structure of the Study

In this study, a set of nominal conditions (runway configurations, demand characteristics, and ATC rules) is defined and a set of parameters identified that may be changed as a result of some technical improvement to the ATC system. These parameters are varied and the resulting changes in airfield capacity computed.

2.3.1 Nominal Conditions

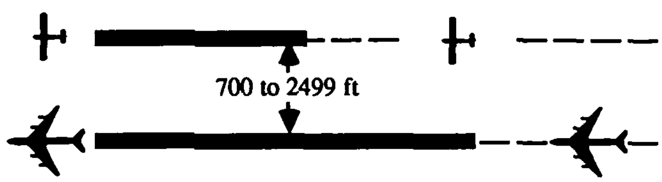
As noted in Section 2.1, when computing airfield capacity one must specify runway configuration, demand, and operating conditions. To keep the results at a manageable level, in this study a limited set of combinations of these factors was analyzed. At the same time, the analysis is designed to be representative of conditions that exist at airports today.

2.3.1.1 Runway Configurations. Three runway configurations were selected as being fairly representative of the types of runway configurations that exist at most major airports. These runway configurations, depicted in Figure 2-1, are:

- Single runway. This is (obviously), the most basic runway configuration. Most major airports have multiple runways; if they can be operated independently, the capacity is simply the number of runways times the capacity of a single runway.

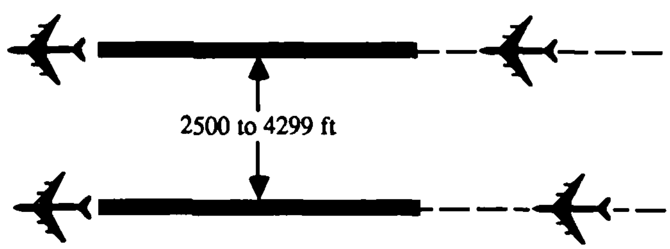
1. Single runway

- Wake vortex-dependent.
- Single-stream in IFR.



2. Dual parallel runways ("Duals")

- Wake vortex-independent.
- Dependent arrivals in IFR.



3. Parallel runways

FIGURE 2-1
RUNWAY CONFIGURATIONS ANALYZED

- Parallel runways with spacing of 700 to 2499 feet. These cannot be operated independently in either VFR or IFR, and consequently have capacity less than twice that of a single runway. In IFR, only single arrival and single departure streams may be operated (although arrivals and departures may use different runways). In VFR, arrivals and departures may be operated to both runways simultaneously, but the wake vortices of aircraft on the other runway must be taken into account.

- Parallel runways with spacing of 2500 to 4299 feet. These may be operated independently for both arrivals and departures in VFR, since they are wake-vortex independent. They are of interest because under IFR they must be operated in dependent fashion for separation assurance.

Two additional runway configurations that are prevalent, converging and intersecting runways, were not analyzed. Converging runways operate independently in VFR (and in IFR, where allowed under "TERPS+3"); their capacity is the sum of two independent runways. Intersecting runways are usually operated with arrivals on one runway, departures on the other; their capacity is similar to that of a single runway except that ROT is less of a factor.

2.3.1.2 **Demand Characteristics.** There are two demand characteristics of interest: aircraft fleet mix and proportion of arrivals to departures. The fleet mix is of interest because the characteristics of aircraft (e.g., their speeds and the severity of their wake vortices) have an effect on ATC operations, and thus on the capacity of the airport. The proportion of arrivals to departures (expressed in terms of percent arrivals) is of interest because a given number of arrivals is not interchangeable with the same number of departures.

Aircraft Characteristics. The two key characteristics of aircraft that affect capacity are its wake vortex class and its airspeed on final approach. The wake vortex class determines the required minimum separation between aircraft; differences between airspeeds may require that additional spacing be provided when lining up aircraft on final approach. For modeling purposes, aircraft are divided into 4 classes (A, B, C, and D) as shown in Table 2-1. Four aircraft final-approach speeds are assumed, ranging from 100 to 140 kts. There are only three wake vortex classes (small, large, and heavy); as shown in the table, model classes B and C are in the same wake vortex class (II-large).

Typical aircraft in each class are: Model class A, Swearingen SW-4 "Metro"; B, Convair 580; C, Boeing 727; D, Lockheed L-1011. The fleet mix assumed consists of 15 percent class A, 20 percent B, 55 percent C, and 10 percent D. While there is no "typical" fleet mix that applies at all airports, this fleet mix is fairly representative of those found at many major airports.

TABLE 2-1
AIRCRAFT CLASSIFICATIONS

MODEL CLASS	AIRCRAFT TYPE	WAKE VORTEX CLASS	FINAL APPROACH SPEED
A	Small Aircraft	I Small	100 Kts
B	Large Prop	II Large	110 Kts
C	Large Jet	II Large	130 Kts
D	Heavy Jet	III Heavy	140 Kts

Percent Arrivals. A runway can accomodate a certain number of arrivals, or a certain number of departures, or some combination of both. The capacity of a runway configuration is thus a set of numbers. This can be illustrated graphically, as in Figure 2-2. The vertical axis represents number of arrivals; the horizontal axis, departures. A runway configuration's capacity is the sum of the number of arrivals and departures at any point along the "curve" A-B-C-D. Arrivals-only capacity is point A. Generally, when in an arrival-priority operation, some departures can be interleaved, up to a limit represented by point B. Beyond this, departures can be accommodated only by reducing the number of arrivals until the operation is departures-only (point D). Capacity, as defined in this document, is the sum of the number of arrivals and number of departures at a specified point on this curve. Rather than provide complete capacity curves for all cases, this study computes capacity at three key points: (1) arrivals-only (point A on the capacity curve); (2) departures-only (point D); and (3) 50 percent arrivals, 50 percent departures (point C).

2.3.1.3 ATC Rules and Procedures. An air traffic controller is concerned with processing aircraft to or from a runway while maintaining safe separation between aircraft. In the aircraft, the pilot is concerned with making a safe takeoff or landing and proceeding to his destination. ATC rules and procedures are designed to support these objectives while ensuring safety, in all weather conditions. These rules and procedures are documented in the FAA ATC Handbook, which specifies requirements for visual and radar procedures. Supplementary FAA orders and airport-specific guidelines indicate which rules (IFR on VFR) must be applied and under which weather conditions. Many procedures operate under very specific ceilings and/or visibilities (for example, IFR converging runway operations). However, when analyzing ATC operations two broad categories can be identified: visual and instrument procedures, or VFR and IFR.

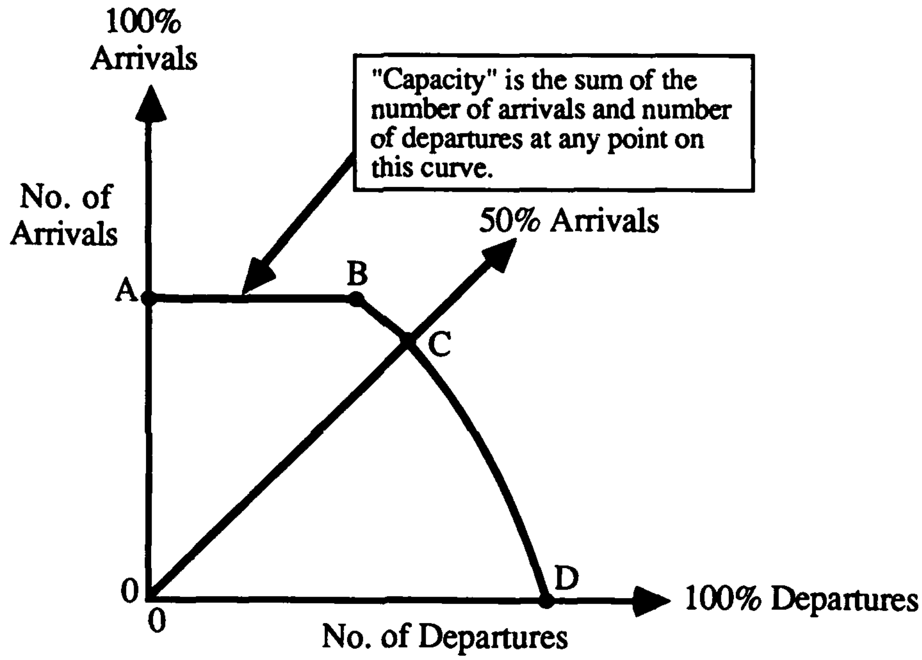


FIGURE 2-2
CAPACITY AS A FUNCTION OF PERCENT ARRIVALS

In this study, capacity is computed for each condition: VFR, which is the subject of Section 3; and IFR, which is the subject of Section 4. Weather conditions assumed are, for VFR, visibility sufficient to allow visual approaches and use of visual separations along the entire final approach and on the airport surface. (In the model, 5 nmi forward visibility and 5000 ft. ceiling is used.) For IFR, visibility is assumed to be low enough to require Instrument Landing System (ILS) approaches and use of radar separations and other non-visual control procedures by the controller. (In the model, 0 nmi and 0 ft. are used.)

2.3.2 Variables Analyzed

The parameters that were varied to determine potential increases in airport capacity are those that have the potential to be affected through some technical improvement to the ATC system. These parameters are:

- Interarrival separation minimums. This is the minimum separation allowed between two aircraft on final approach to the same runway (or different runways, for dependent parallel operations). The model assumes that this separation is violated 5 percent of the time. For modeling purposes, a VFR set of values is needed; thus, both IFR and VFR have separation "minima".

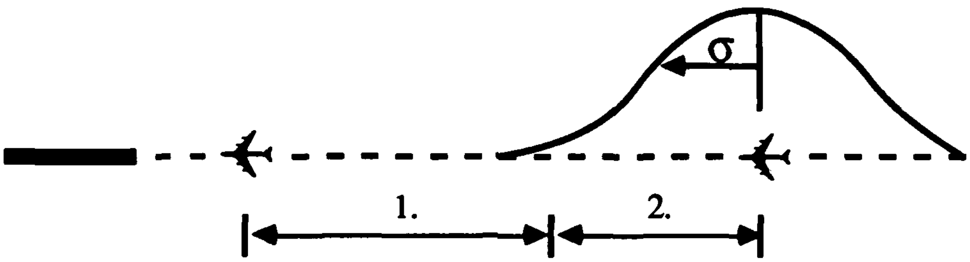
- Departure separation minimums. This is the required separation between two departing aircraft. In VFR, ATC rules specify minimum distances prior to release of the next departure; for modeling purposes, these have been converted to observed time separations. In IFR, ATC rules specify time between departures.

- Variability in Interarrival Time. "Lining up" aircraft on final approach is a manual operation in which the controller must allow for variations in aircraft speeds and turn rates, even for the same aircraft type. Actual spacing consists of two components, as illustrated in Figure 2-3: a minimum spacing (in IFR, the 3, 4, 5, 6 nmi rule; in VFR, whatever spacing the pilot finds acceptable), plus some extra space to accommodate the variations.

- Arrival Runway Occupancy Time (mean and variation). This is the time from when an aircraft crosses the threshold until it exits the runway.

- Departure Runway Occupancy Time (mean and variation). This is the time from when an aircraft starts its takeoff roll until it is airborne.

- Length of common final approach. As aircraft travel along the final approach path, speed differences result in changed separations. A slower aircraft traveling behind a faster one will have a larger separation when crossing the threshold than existed



1. Minimum separation standard: 3, 4, 5, 6 nmi rule

2. Extra spacing added by the controller as a buffer to accommodate variations in spacing ("delivery error")

FIGURE 2-3
COMPONENTS OF INTERARRIVAL SPACING

when it turned on to the final approach path. This "extra" spacing results in a slightly lower capacity than would be achievable if all aircraft traveled the same speed.

In the analysis of Sections 3 and 4, the baseline values of these parameters are identified and today's capacity computed. The values of these parameters are then individually varied and the resulting change in capacity noted. Variations fit two basic scenarios:

1. A theoretical, unrealistic upper bound on capacity computed by setting parameters to their absolute minimums.

2. A "realistic" upper bound computed by setting parameters halfway between the baseline (today) and the unrealistic upper bound values.

The values of the parameters are then changed simultaneously, and the resulting VFR and IFR capacities computed to obtain an estimate of realistic/unrealistic expectations for total capacity increases in the future.

3.0 VFR CAPACITY INCREASES

Potential increases in VFR capacity are computed for each of the runway configurations--single, dual, and parallel runways, as defined in Section 2--based upon reductions in parameter values that might result from improved airfield and terminal-area operations. These increases are computed from a baseline capacity representing today's VFR operations.

3.1 Today's VFR Operations

3.1.1 Baseline VFR Parameter Values

In addition to the baseline characteristics defined in Section 2, there are specific parameter values, based upon today's VFR operations, which determine today's VFR capacity. These input values for use in the airfield capacity model are taken from Reference 5, and include observed separations between aircraft, runway occupancy times, and IAT variability. A complete listing of the values of these variables as used in the model to calculate the baseline VFR capacity is contained in Appendix A; a short description of these values is included here to assist in interpretation of the results of parameter changes.

Separations. Under today's VFR operations, the controller points out the leading aircraft to each pilot making an approach; the pilot assumes the responsibility for maintaining separation, which allows lower separations than if radar separations were maintained by the controller to the threshold. As such, there are no formal separation "requirements" on final approach in VFR; instead, observed values are used in the modeling process. The Airfield Capacity Model requires "minimum" separations corresponding to the 3, 4, 5, 6-nmi rules that apply in IFR; observed equivalents in VFR are 1.9, 2.7, 3.6, and 4.5 nmi.

For separations between departures, the requirement is that the previous departure must be a specified distance down the runway (from 3000 to 6000 feet, depending on aircraft class) and airborne. The model is calibrated on the observed time for this to occur; values range from 30 to 50 seconds.

Runway Occupancy Time. Observed arrival ROTs vary from airport to airport, and even from runway to runway, depending on such factors as exit locations and the location of the arriving aircraft's gate. The baseline arrival ROTs used are those observed in the reduced longitudinal separation demonstrations (References 6 and 7); at 40, 40, 45, 50 seconds (model class A, B, C, D) with an s.d. of 10 seconds (all classes), they represent the lowest ROTs observable today. Because ROTs are higher at many airports (Reference 8), this parameter will be varied to higher (as well as lower) values.

Departure ROT, on the other hand, is quite consistent from airport to airport. Baseline values used were 35 seconds for aircraft classes A and B, and 40 seconds for classes C and D, with an s.d. of 6 seconds (all classes).

Other Parameters. Other parameters analyzed include IAT variability and length of common final approach. IAT variability, the measure of variability in final approach spacing, is expressed in units of time. The currently observed value, used as the baseline in this study, is 18 seconds (1 s.d.). Length of the common final approach for individual aircraft pairs is based upon a final approach path of 3 nmi for aircraft classes A and B, and 5 nmi for classes C and D. This is consistent with VFR operations in which, typically, small aircraft are brought in on final closer to the threshold while large and heavy jets are given longer final approaches.

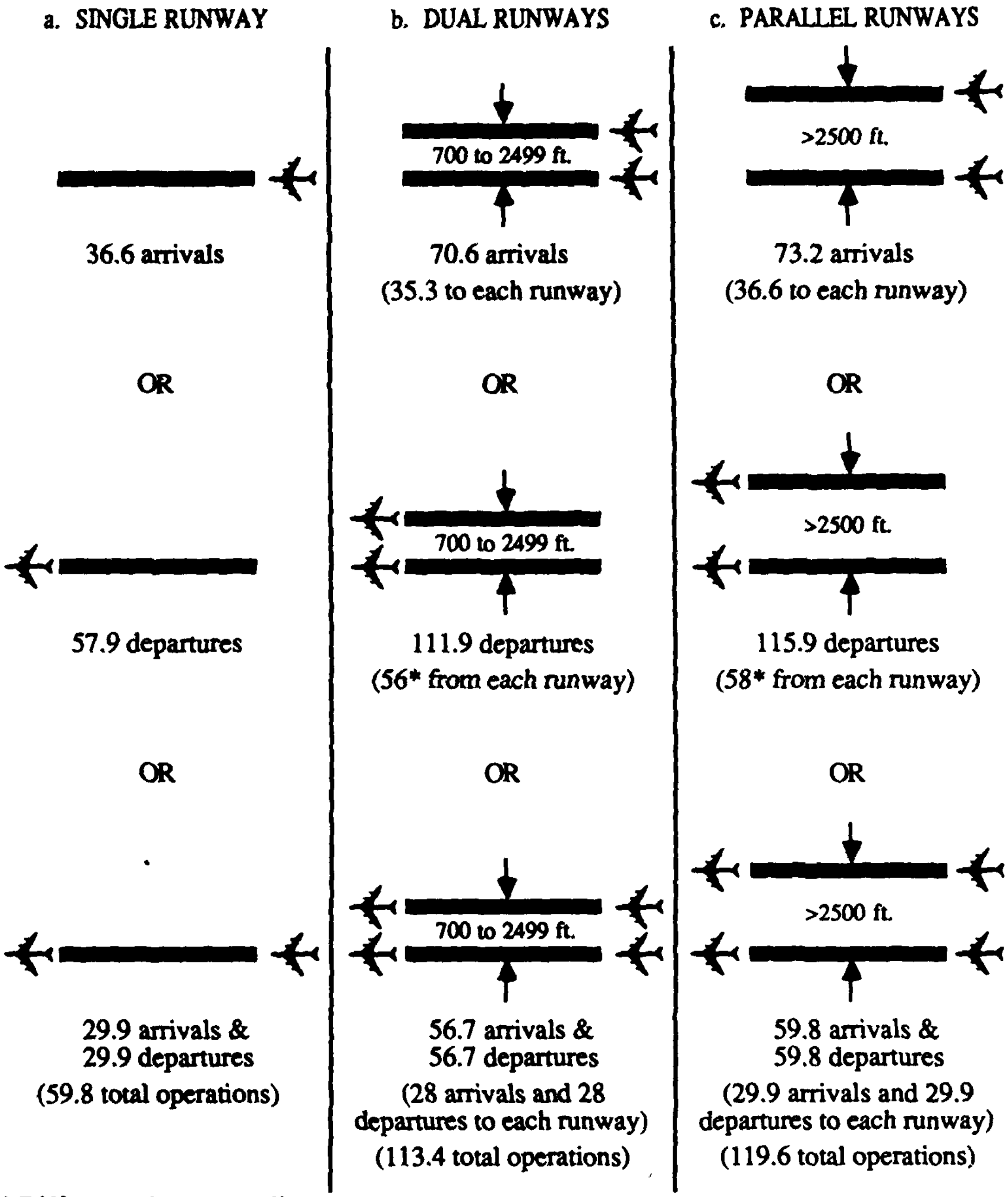
3.1.2 Today's VFR Capacity

These parameter values combined with the assumptions described in Section 2, produce the VFR capacities of the three runway configurations that were analyzed, as shown in Figure 3-1. These capacities represent the baseline values from which computations of potential capacity increases will be computed. While these values are generally indicative of the capacity of airports with these runway configurations, differences should be expected at individual airports because of variations in fleet mixes, ROTs, and other factors.

Single Runway Capacity. The VFR capacity of a single runway is illustrated in Figure 3-1a. In VFR, a single runway can accommodate as many as 36.6 arrivals/hour; or almost 58 departures/hour; or 29.9 arrivals and 29.9 departures. (It should be noted that while achieving the 36.6 arrivals, a certain number of departures could be interleaved; but since we are interested in the number of arrivals that can be handled, only the arrivals are shown.)

"Dual" Runways. The capacity of dual runways (runways spaced 700 to 2499 feet apart) is illustrated in Figure 3-1b. This configuration accommodates 70.6 arrivals, or 111.9 departures, or 56.7 arrivals and 56.7 departures. Note that these values are not quite double that of the single runway capacity. The difference is attributable to wake vortex considerations, which require that an aircraft (either arrival or departure) be separated not only from the one in front of it on the same approach, but also the one on the adjacent approach. This occasionally requires additional separation between aircraft on the same approach beyond what is normally required, with a slight loss in capacity.

Parallel Runways. Parallel runways spaced more than 2500 feet may be operated independently in VFR. The net result is that the capacity of such runways, shown in Figure 3-1c, is twice that of a single runway.



* Difference due to rounding

FIGURE 3-1
TODAY'S VFR CAPACITY

The effect of changes in the parameters on these baseline capacities will be examined in Section 3.2.

3.2 Effect of Changes in Individual Parameters

This analysis looks at the effect of changing individual parameter values to see the resulting increases, if any, in airfield capacity. Parameters varied are those separation rules and performance parameters that may be susceptible to reductions by means of technical improvements in ATC system operations. The effects on capacity of these parameter changes are plotted in 3 graphs, for arrivals-only, mixed operations (50 percent arrivals, 50 percent departures), and departures-only. The computed capacities for the three runway configurations will be plotted on the same graph. Parameters are (usually) varied to two values, labeled scenarios (i) and (ii); parameter values associated with each of the scenarios are listed in a box beneath the set of graphs. The effect of reduced separations will be covered in Section 3.2.1, and changes in performance parameters in Section 3.2.2.

3.2.1 Separation Rules

Interarrival Separations. The effect of reductions in the observed "minimum" interarrival separations is shown in Figure 3-2a. The two levels of reductions (scenarios (i) and (ii)) that are hypothesized represent reductions of approximately 10 percent, and from 21 to 33 percent, respectively. Reductions in these parameters can only be achieved through technical developments that act on the smallest separations; such developments would have to include reliable wake vortex detection and avoidance, as well as separation assurance.

Should these developments be possible, significant increases in arrival-only capacity result, as shown in the top graph of Figure 3-2a. Reductions in arrival separations to the levels of scenario (i) result in 7 percent increases; scenario (ii), 13-14 percent. There are no increases in mixed operations (50 percent arrivals, 50 percent departures) capacity; today's ROTs limit any increases.

Departure separations. The effect of reductions in departure separation requirements is shown in Figure 3-2b. The scenarios that were examined, as shown under "Scenario Values", represent: (i) reductions of 5 to 10 seconds, with 20-second reductions for heavies (a 17 percent decrease); and (ii) reductions of 10-20 seconds, with 40 second reductions for heavies (a 33 percent decrease). (Potential means to achieve these reductions, for example, would be to shorten the distance requirements--currently 3000 to 6000 feet--to allow 5 to 10 second reductions in observed departure separations, provided that adequate wake vortex detection and avoidance methods exist.) The resultant departure-only capacity increases are quite substantial; the 5 to 10-second reductions produce an 18 percent

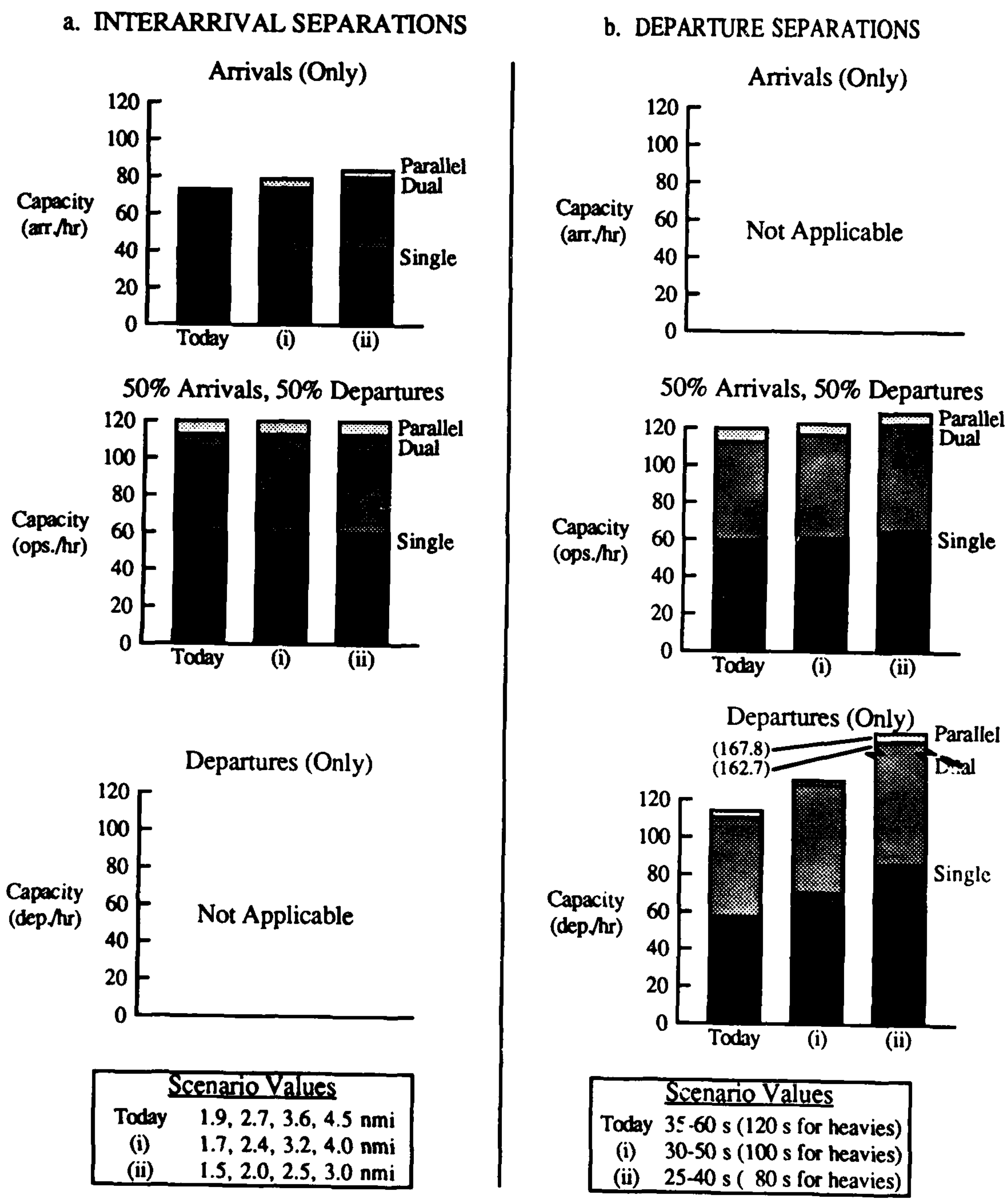


FIGURE 3-2
EFFECT OF REDUCED SEPARATIONS ON VFR AIRFIELD CAPACITY

increase, and the 10 to 20-second reductions, a 45 percent increase. There is only a slight increase in mixed operations capacity, however, again due to runway occupancy limitations.

3.2.2 Performance Parameters

The performance parameters that were varied are arrival and departure ROT mean and variability, IAT variability, and length of common final approach.

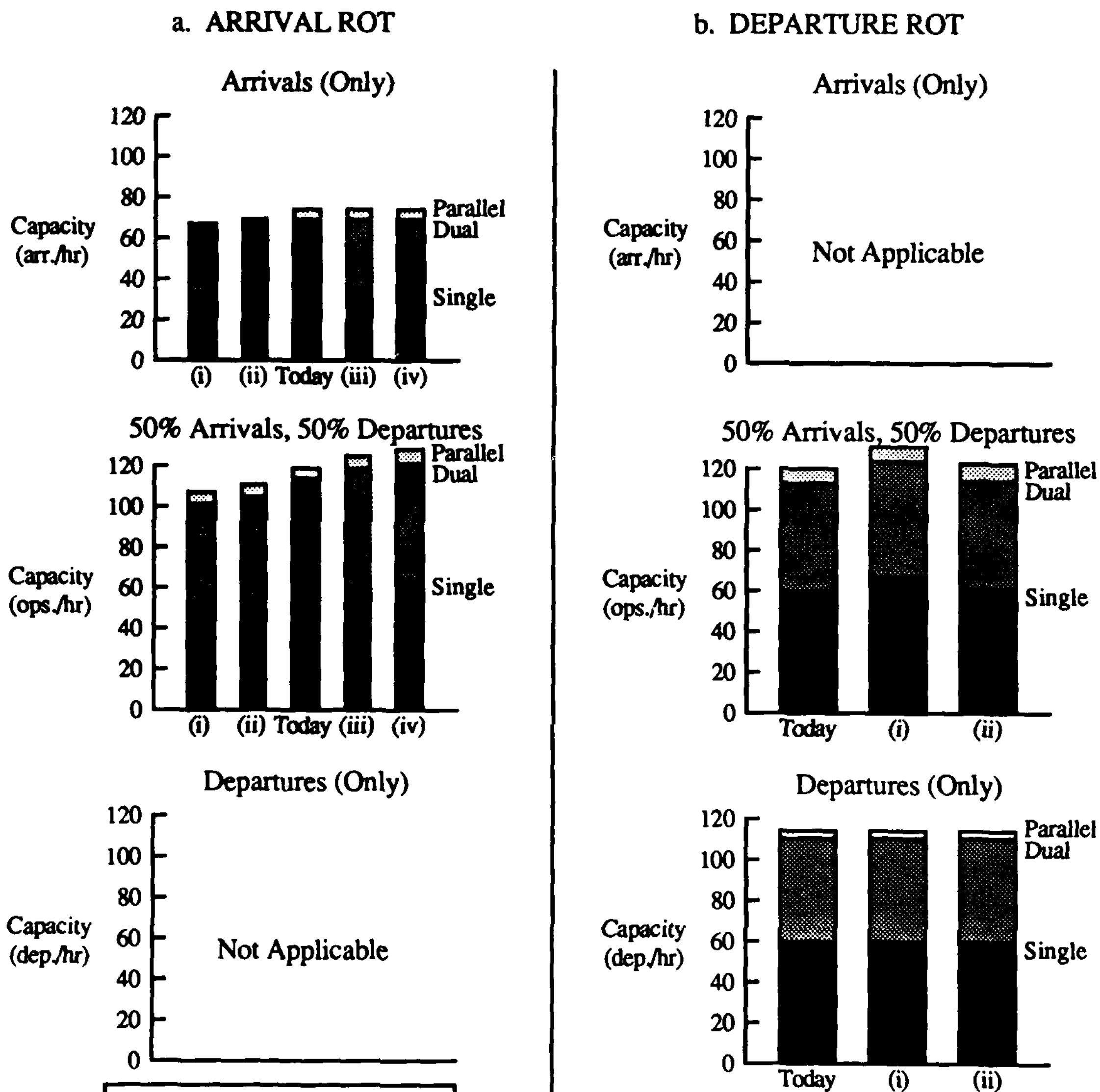
Arrival Runway Occupancy Time. The effect of varying arrival ROT is shown in Figure 3-3a. Both mean and standard deviation were varied simultaneously; a reduction in the mean is assumed to produce a reduction in the variance as well. As can be seen from the first graph, there are no increases in arrivals-only capacity from reducing arrival ROT below 40-50 seconds (scenarios (iii) and (iv)). However, ROTs of 40-50 seconds are not consistently achieved at all airports; at some airports, ROTs can be as high as 45-60 seconds. There is thus some capacity gain to be had by reducing ROT to 40-50 seconds at those airports where it is not currently achieved, as can be seen by the slightly lower capacity for higher arrival ROT (scenarios (i) and (ii)).

Arrival ROT has a significant impact on VFR mixed operations capacity. When arrivals and departures must use the same runway, the principal limitation on capacity is the time aircraft spend on the runway. Reductions in ROT can produce significant gains in mixed operations capacity; as shown in the second graph, a reduction in ROT of 5-10 seconds (scenario (iii)) produces an 8 percent increase in capacity; further reductions produce larger increases.

Departure Runway Occupancy Time. As can be seen by the lower graph in Figure 3-3b, significant decreases in the mean and s.d. (scenario (i)) or only the s.d. (scenario (ii)) of departure ROT have no effect in departure capacity. Departure separations, which are based on the previous aircraft's distance down the runway and whether it is airborne, are larger than ROT. In addition, wake vortex separation requirements must be met for successive departures; thus, departure separations would have to be maintained even if ROT were reduced.

There are, however, capacity increases from reduced departure ROT for mixed operations, as shown in the middle graph. A 10-second reduction in the mean ROT (scenario (i)) produces a 4 percent increase in capacity; a 2-second (33 percent) decrease in the standard deviation (scenario (ii)) produces a 3 percent increase in capacity.

IAT Variability. Figure 3-4a shows the effect on VFR capacity of reducing interarrival time variability by 33 percent (scenario (i)) and by 50 percent (scenario (ii)). The 33 percent reduction results in an 11 percent increase in arrivals-only capacity; the 50 percent reduction,



Scenario Values
(Class A,B,C,D)

(i)	50, 50, 60, 65 s; s.d. = 15
(ii)	50, 50, 55, 60 s; s.d. = 13
Today	40, 40, 45, 50 s; s.d. = 10
(iii)	35, 35, 40, 45 s; s.d. = 8
(iv)	30, 30, 35, 40 s; s.d. = 6

Scenario Values
(Class A,B,C,D)

Today	35, 35, 40, 40 s; s.d. = 6 s
(i)	25, 25, 30, 30 s; s.d. = 4 s
(ii)	35, 35, 40, 40 s; s.d. = 4 s

FIGURE 3-3
EFFECT OF REDUCED RUNWAY OCCUPANCY TIME ON VFR AIRFIELD CAPACITY

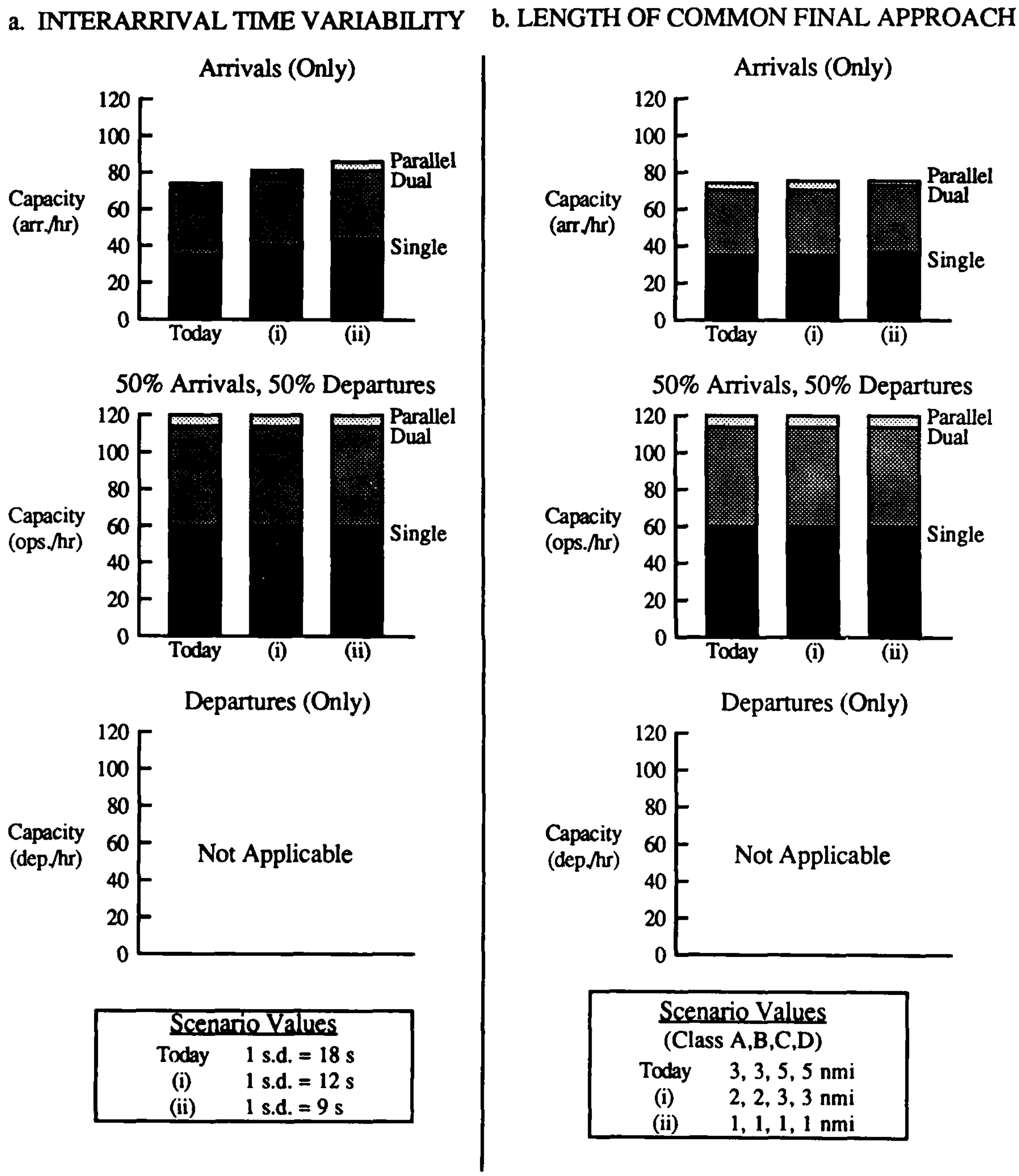


FIGURE 3-4
EFFECT OF REDUCTIONS IN OTHER PARAMETERS ON VFR AIRFIELD CAPACITY

a 17-18 percent increase. Thus, there are significant potential capacity gains in VFR arrival-only capacity from ATC system improvements that would reduce IAT variability.

This is not the case for mixed operations (arrivals and departures on the same runway), however, as shown in the second graph of Figure 3-4a. No capacity increases result because of runway occupancy time limitations; reduction in arrival or departure ROT (or both) would be necessary for increases to be possible from reduced IAT variability.

Length of Common Final Approach Path. The effect of a reduction in the length of the common final approach path, to reduce the impact of speed differentials on capacity, is shown in Figure 3-4b. A substantial reduction in the length of the final approach path, from 3-5 nmi to 2-3 nmi (scenario (i)), produces a small increase in arrival-only capacity of about 1 operation/hour for each runway in the configurations analyzed (a 3 percent increase). Further reductions (scenario (ii)) produce similar small increases. There are no increases in mixed operations capacity, again due to limitations of runway occupancy time.

3.2.3 Summary of the Effects of Changes in Parameters

A summary of the effect on VFR capacity of variations in the individual parameters is shown in Figure 3-5. The graph shows percentage increases in capacity for each type of operation (arrival-only, mixed operations, or departures-only) from reducing parameters to the intermediate (scenario (i)) values (except IAT variability, which was reduced 50 percent (scenario (ii)). Since percentage increases are fairly constant for each of the runway configurations analyzed, only one bar is shown; a percentage range indicates where increases are different for individual configurations. For example, if IAT variability is reduced from 18 seconds (1 s.d.) to 9 seconds, then VFR arrivals-only capacity would increase 17-18 percent (depending on runway configuration). Likewise, if interarrival separations, currently observed to be in the range of 1.9-4.5 nmi, were reduced to 1.7-4.0 nmi, then VFR arrivals-only capacity would increase 7 percent.

Arrivals-Only Capacity. As shown in Figure 3-5a, the factors with the greatest impact on arrival-only capacity are those that determine average separation between aircraft on final approach--IAT variability, interarrival separaticns, and the extra separation resulting from speed differences on final approach. The most significant factor is interarrival time variability, where a 50 percent reduction would result in a 17-18 percent capacity increase. Additional increments would come from reduced arrival separations and from a reduced common final approach path. It should also be recognized that, although there are no capacity gains from reducing ROT below the baseline values, there are potential increases from consistently achieving 40-50 second runway occupancy times.

a. ARRIVALS - ONLY

Parameter	Reduction From	Reduction To	Percentage Increase In VFR Capacity
IAT variability	18 s	9 s	17-18%
Interarrival separations (observed)	1.9 - 4.5 nmi	1.7 - 4.0 nmi	7%
Common final	3-5 nmi	2-3 nmi	2-3%
Arrival ROT mean variability	40-50 s 10 s	30-40 s 5 s	0% 0%

b. 50% ARRIVALS, 50% DEPARTURES

Parameter	Reduction From	Reduction To	Percentage Increase In VFR Capacity
Arrival ROT mean	40-50 s	30-40 s	8-9%
Departure ROT mean variability	35-40 s 6 s	25-30 s 4 s	4% 3%
Departure separations	50-60 s (120 s / heavies)	40-50 s (100 s / heavies)	3%
IAT variability	18 s	9 s	<1%
Arrival ROT variability	10 s	5 s	<1%
Interarrival separations	1.9-4.5 nmi	1.7-4.0 nmi	0%
Common final	3-5 nmi	2-3 nmi	0%

c. DEPARTURES - ONLY

Parameter	Reduction From	Reduction To	Percentage Increase In VFR Capacity
Departure separations	50-60 s (120 s / heavies)	40-50 s (100 s / heavies)	18%
Departure ROT mean variability	35-40 s 6 s	25-30 s 4s	0% 0%

FIGURE 3-5
INCREASES IN VFR CAPACITY FROM PARAMETER REDUCTIONS

Mixed Operations (50 Percent Arrivals) Capacity. The principal limitation on VFR mixed operations (50 percent arrivals) capacity, as shown in Figure 3-5b, is runway occupancy time, where a 10-second decrease in mean arrival ROT produces an 8-9 percent increase in capacity; a 10-second decrease in mean departure ROT, a 4 percent increase in capacity; and a one-third decrease in the variability of departure ROT, a 3 percent increase in capacity. Reductions in other parameters will have a negligible or no effect on mixed operations unless there are corresponding reductions in ROT.

It is interesting to note that reductions in some of the key variability parameters, such as IAT variability and variability in arrival ROT, produce only negligible capacity gains. Rather than representing unused capacity, this variability is used to advantage by a controller: Given today's mean arrival and departure ROT, a controller can request an average interarrival separation such that, on average, one departure can be released between each arrival pair. The process is variable, however. If the arrival separation is below average and the ROT above average, no departure may be released. If the arrival separation is above average and the ROT below, then multiple departures may be released. The net result is still one departure for every arrival. If IAT and arrival ROT variability were reduced to 0.0, a controller could guarantee that one departure be released between each pair of arrivals; however, the total number of operations would not increase.

Departure-Only Capacity. The only factor that provides a significant increase in departures-only capacity (Figure 3-5c) is departure separations; a 14 to 20 percent decrease would produce an 18 percent increase in departure-only capacity.

3.3 Overall Expectations for Capacity Increases

What, then, are the overall capacity increases to be expected from efforts to change these parameters? The results, of course, will vary depending on the changes in the parameters that are actually achieved. It is still possible, however, to estimate the magnitudes of capacity gains that are realistic (and unrealistic).

3.3.1 Theoretical Upper Bound

By setting the parameters to their lower bounds (which in many cases is zero), an estimate of the theoretical upper bound of capacity increases can be obtained. This upper bound should not be seen as being achievable; rather, it is a useful figure to characterize whether another estimate of capacity increases is realistic. (Any estimate coming near or exceeding these values should be considered unrealistic.) The estimate of this theoretical upper bound is based on reductions in the variability parameters to 0.0, and separations to values judged (arbitrarily) to be absolute minimums.

The theoretical upper bound on increases in VFR capacity is shown in Figure 3-6. Included is a list of the parameter values the scenario is based upon. The upper bound on increases in arrivals-only capacity is 44-46 percent, depending on runway configuration; for departures, 18 percent (by reducing departure separations). No capacity increases are possible for mixed operations, however, unless mean runway occupancy time is reduced; consequently, Figure 3-6 shows the upper bound for mixed operations capacity if arrival runway occupancy time is reduced to unrealistically low values of 15, 15, 20, 25 seconds (class A, B, C, D). The theoretical capacity increase for mixed operations, with arrival runway occupancy reduced to these values, is 72-79 percent.

3.3.2 Realistic Upper Bounds

A more realistic limit on the potential for capacity increases, obtained by setting the parameters to intermediate values representing approximately 50 percent reductions in variabilities and smaller reductions in parameters such as ROT and separation values, is shown in Figure 3-7. A list of the parameter values this scenario represents is shown in the figure. Capacity increases range from 18 percent for departure-only operations to 22 percent for arrival-only operations. Since the parameter values used are very optimistic, these values are really an upper bound on realistic expectations for capacity increases with reasonable improvements in ATC system performance. These are general increases; actual capacity increases at specific sites will vary due to local conditions and any external factors that may apply at that particular airport.

3.4 Conclusions for VFR

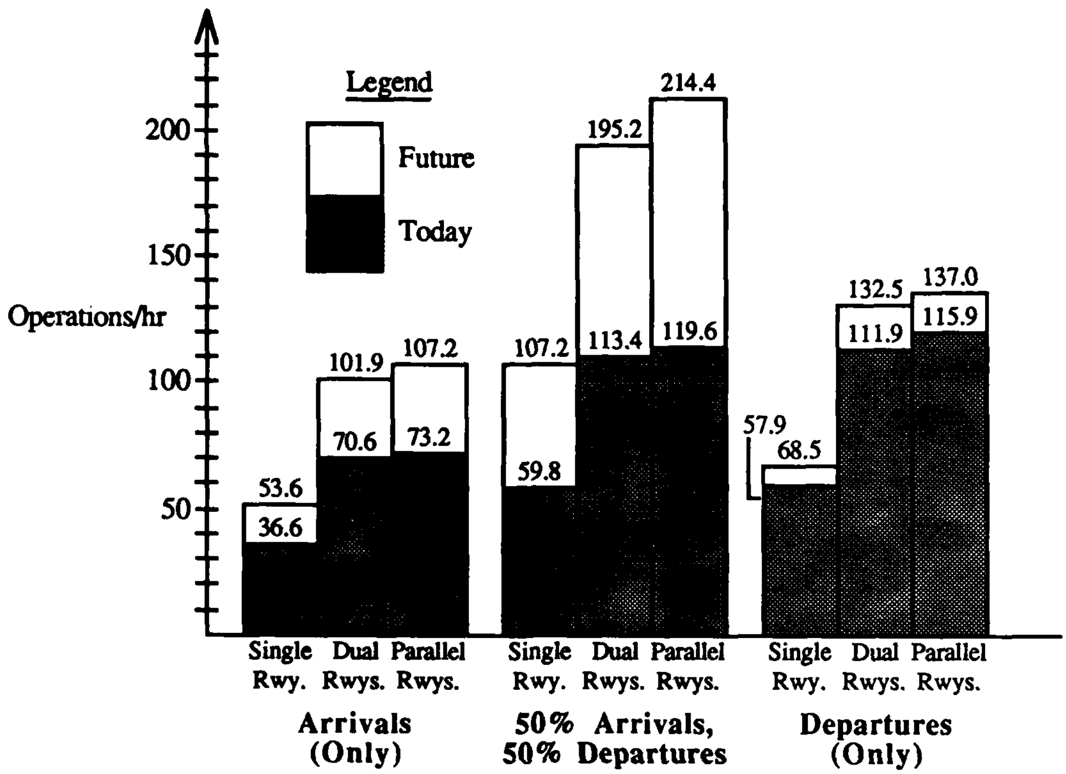
Based on this analysis, the following conclusions are drawn for VFR capacity:

1. There is potential for VFR capacity increases through ATC system improvements. A realistic estimate of the capacity increases from these types of improvements is approximately 18-22 percent, depending on whether the operation is arrivals-only, mixed, or departures-only.

2. Most of the potential gain, for arrivals, comes from reduced interarrival time variability (17-18 percent).

3. All of the increase in departure-only capacity comes from decreasing departure separation requirements, allowing a reduction in the average time between release of successive departures.

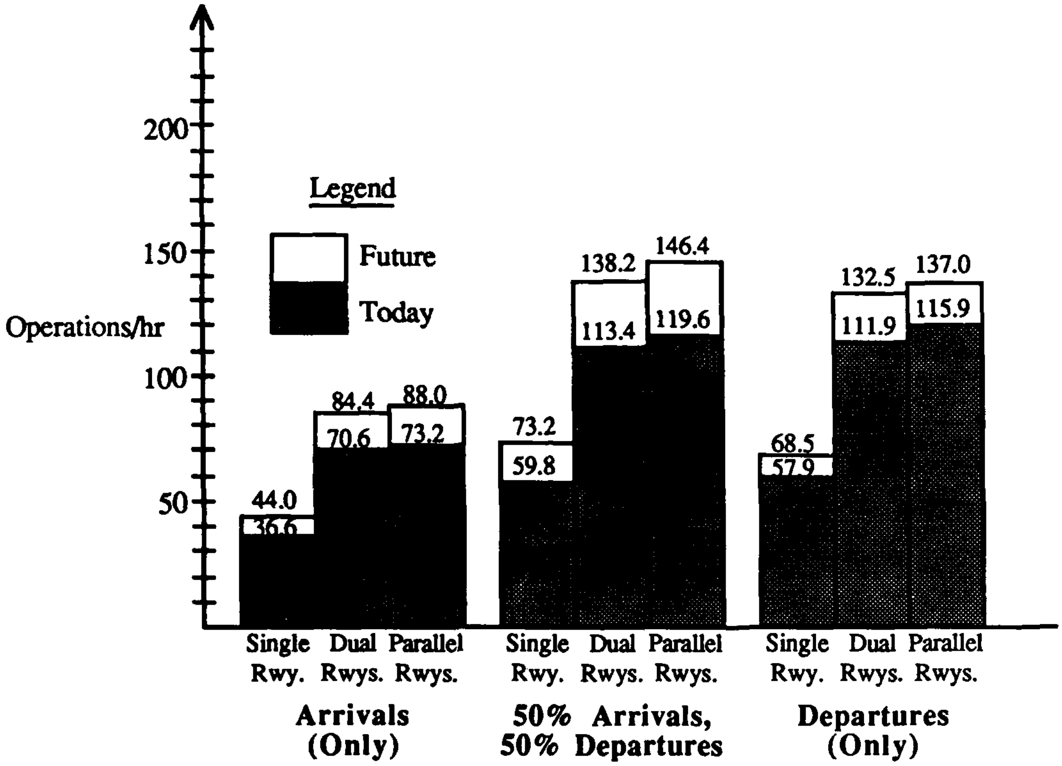
4. Capacity increased for mixed operations (50 percent arrivals) are limited unless there are reductions in runway occupancy time (either arrival, departure, or both).



<u>Assumed Basis for Capacity Increases</u>

Parameter	Reduction From	Reduction To
Arrival separations	no change	
Departure separations	35-60 s (120 s for heavies)	25-40 s (80 s for heavies)
IAT variability (1 s.d.)	18 s	0 s
Arrival ROT -- mean	no change	
(mixed operations(class A, B, C, D))	(40, 40, 45, 50 s)	(35, 35, 40, 45 s)
-- variability (1 s.d.)	10 s	5 s
Departure ROT -- mean	no change	
-- variability (1 s.d.)	6 s	0 s
Length of common final approach	3-5 nmi	2-3 nmi

FIGURE 3-6
THEORETICAL UPPER BOUND ON VFR CAPACITY INCREASES



Assumed Basis for Capacity Increases

Parameter	Reduction From	To
Arrival separations	no change	
Departure separations	35-60 s (120 s for heavies)	30-50 s (100 s for heavies)
IAT variability (1 s.d.)	18 s	9 s
Arrival ROT -- mean (class A, B, C, D)	40, 40, 45, 50 s	35, 35, 40, 45 s
-- variability (1 s.d.)	10 s	5 s
Departure ROT -- mean	35-40 s	30-35s
-- variability (1 s.d.)	6 s	4 s
Length of common final approach	3-5 nmi	2-3 nmi

FIGURE 3-7
"REALISTIC" UPPER BOUND ON VFR CAPACITY INCREASES

4.0 IFR CAPACITY INCREASES

Potential increases in VFR capacity are computed for each of the runway configurations--single, "dual", and dependent parallel, as defined in Section 2--based upon reductions in parameter values that might result from improvements in airport and terminal-area operations.

4.1 Today's IFR Operations

4 1.1 Baseline IFR Parameter Values

In addition to the baseline characteristics described in Section 2, there are specific parameter values, based upon today's IFR operations, which determine today's IFR capacity. These baseline input values for computation of IFR capacity are taken from Reference 5. The separation values used are those specified by the ATC handbook (Reference 4), including the diagonal separation requirement for aircraft making dependent parallel approaches. Values for IAT variability and ROT are the same as for VFR. A detailed listing of the parameter values and results of the computation process can be found in Appendix B; a short description of the values used is provided here to assist in interpretation of the results of changes in parameters.

Separations. Separation values used are those specified by the ATC handbook. For arrivals, the 3-nmi radar separation requirement and 4, 5, and 6-nmi wake vortex separations are applied between aircraft on the same approach, and a 2-nmi diagonal is applied between aircraft on adjacent approaches (for runway spaced 2500 to 4299 ft.). For departures, the ATC handbook specifies time separations between successive departures of 1 minute, with 90 seconds between heavies and 2 minutes for all other aircraft behind heavy jets.

Other IFR separation requirements applied in the model include the requirement for a preceding arrival to be 2 nmi from the threshold to release a departure on the same or a close-parallel runway; and the requirement for the previous arrival to have exited the runway (or be over the threshold if arrivals are using a close-parallel runway) to release a departure. However, variations in these rules were not investigated.

Runway Occupancy Time. In the absence of severe weather conditions such as rain or snow, ROTs are observed to be the same in IFR as in VFR. Consequently, the same baseline ROTs were used for IFR that were used for VFR, which are the ROTs observed in the reduced longitudinal separation demonstrations (References 6 and 7): means of 40, 40, 45, and 50 seconds for model classes A, B, C, and D, with an s.d. of 10 seconds. Values above, as well as below this baseline, were examined. Departure ROTs that are the same as in VFR were also used: means of 35 seconds for model classes A and B and 40 seconds for C and D, with an s.d. of 6 seconds.

Other Parameters. A 1 s.d. value of 18 seconds was used for IAT variability under IFR, the same as for VFR. The length of the common final approach path was determined by assuming that all aircraft follow a typical ILS approach, with 2 nmi on-centerline prior to an outer marker that is 5 nmi from the threshold. This results in a 7-nmi common final path.

4.1.2 Today's IFR Capacity

The baseline values of the parameters described above, combined with the assumptions in Section 2, produce the IFR capacities of the three runway configurations shown in Figure 4-1. These capacities represent the baseline values from which potential increases will be computed. While these capacities are generally indicative of the IFR capacity of airports with these particular runway configurations, the IFR capacity of particular airports will differ from these values because of variations in fleet mixes, ROTs, and other factors.

Single Runway Capacity. The IFR capacity of a single runway is illustrated in Figure 4-1a. In IFR, a single runway can accommodate 26.6 arrivals/hour; or almost 55 departures per hour; or 26.6 arrivals and 26.6 departures each hour. (Under arrival-priority or mixed operations, additional departures--even in excess of 26.6--can be operated.)

"Dual" Runways. Today's IFR capacity of dual runways (runways spaced 700 to 2499 feet apart), shown in Figure 4-1b, is exactly the same as that of a single runway. This is because under IFR, only single arrival and/or departure streams may be operated to runways spaced less than 2500 feet.

Dependent Parallel Runways. Under IFR, runways spaced 2500 to 4299 feet apart may be operated in dependent fashion with 2-nmi spacing for arrivals, and independently for departures. The capacity of this configuration, shown in Figure 4-1c, is 36.9 arrivals; or 109.6 departures; or 36.9 arrivals and 36.9 departures. (Again, in IFR more than the 36.9 departures can be operated without reducing the number of arrivals.)

The effect of changes in parameter values on these runway capacities will be examined in Section 4.2.

4.2 Effect of Changes in Individual Parameters

This part of the analysis examines the effect on capacity of changing certain individual parameters. The parameters that were varied for the IFR analysis are those that may be susceptible to reductions through technical improvements in ATC operations. As with the VFR analysis, parameters are usually varied to two values, labeled scenarios (i) and (ii), and the results plotted in three graphs: arrivals-only, mixed operations, and departures-only; single, dual, and dependent parallel

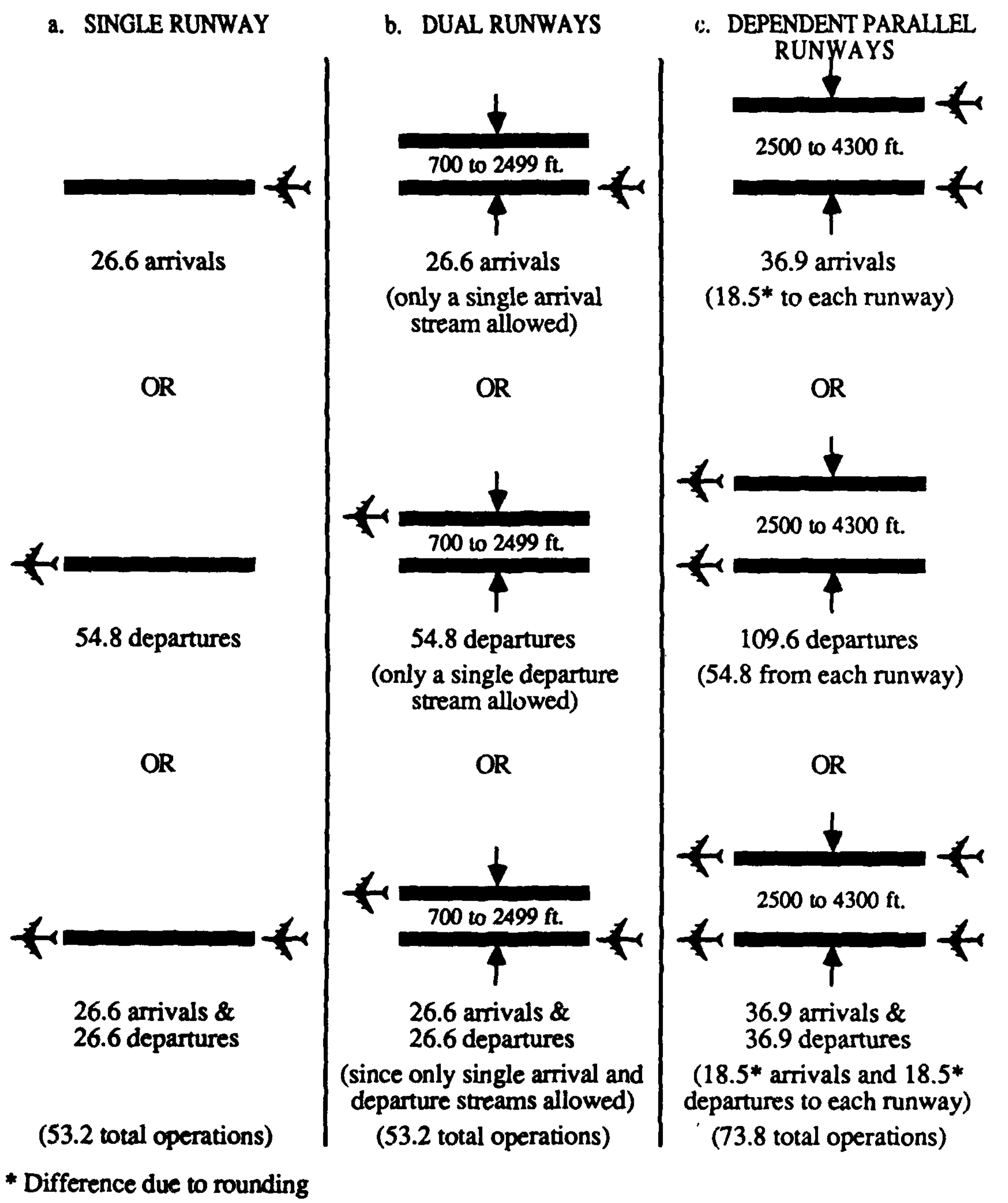


FIGURE 4-1
TODAY'S IFR CAPACITY

capacity are plotted on the same graph. Parameter values for the scenarios are listed at the bottom of each set of graphs. The effect of reduced separations is shown in Section 4.2.1, and reductions in performance parameters in Section 4.2.2.

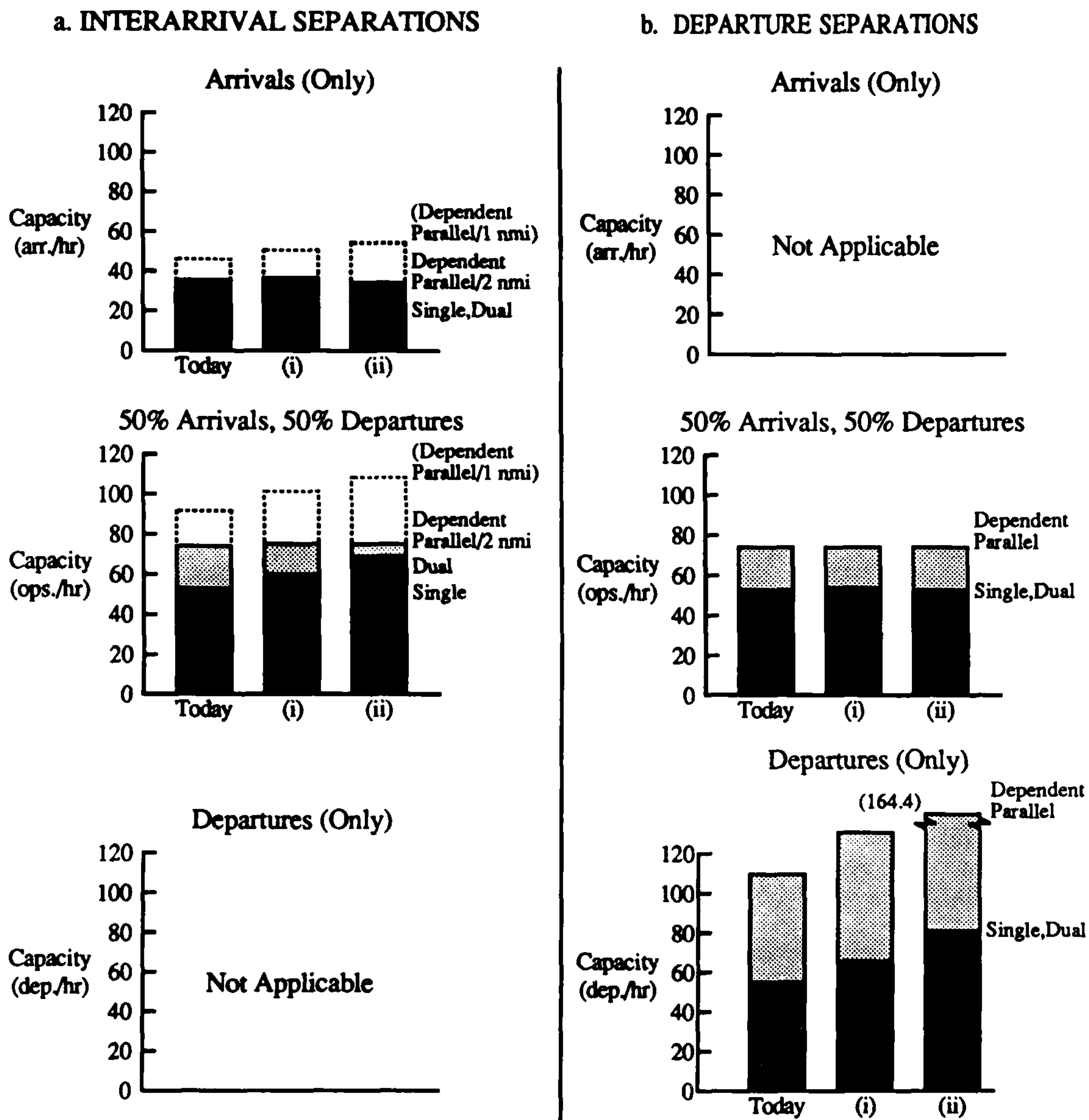
4.2.1 Separation Rules

Interarrival Separations. There are two parameters of interest: longitudinal separation minima (between aircraft on the same approach) and lateral (diagonal) separation (between aircraft on adjacent approaches). The two sets of longitudinal separation reductions that were examined are: (i) reduction of the 3-nmi radar minimum to 2½ nmi coupled with a 1-nmi reduction in the wake vortex requirements (from 4, 5, 6 nmi to 3, 4, 5); and (ii) reductions in the requirements to approximately VFR values: a 2-nmi radar minimum and 2½, 3, 4-nmi wake vortex rules. The resulting capacity increases are shown in Figure 4-2a.

For single and dual runways (single arrival streams), these two scenarios result in 15 percent and 34 percent increases in arrival-only capacity, as shown in the first graph of Figure 4-2a. Dependent parallel capacity increases are negligible, however; this is because the determining factor in dependent parallel operations is the 2-nmi diagonal spacing rule, which enforces a separation between aircraft on the same approach that is larger than the longitudinal spacing requirements (except for the largest wake vortex requirements of 5 and 6 nmi, which occur infrequently).

The capacity increases for mixed operations are shown in the second graph of Figure 4-2(a). For single runways, the increase is small (approximately 3 percent); this is because of runway occupancy time limitations when both arrivals and departures must use the same runway. Dual runways allow arrivals and departures to use different runways; consequently, capacity increases are larger (15 percent and 30 percent for the two scenarios, respectively). Again, dependent parallel operations are constrained by the 2-nmi diagonal rule, so their capacity is not increased.

If the diagonal separation requirement for dependent parallel runway operations is reduced to 1 nmi, then the capacity increases indicated by the unshaded bars (denoted by the dashed lines) result. Arrivals-only capacity will increase by 25 percent (from 36.9 to 46.2 aircraft/hour) immediately; no reductions in any other parameters are required. Further increases in arrival-only capacity result if longitudinal separations are also decreased, as shown in the figure. Reductions to 2½ nmi radar minimum and 3, 4, 5 nmi wake vortex separations increase arrival-only capacity by an additional 10 percent (above the capacity with 1 nmi spacing); reductions to 2 nmi radar and 2½, 3, 4 nmi wake vortex rules, by 16 percent. Similar increases will also result for mixed operations.



Scenario Values		
Today	Radar 3 nmi;	wake vortex 4,5,6 nmi
(i)	Radar 2.5 nmi;	wake vortex 3,4,5 nmi
(ii)	Radar 2 nmi;	wake vortex 2.5,3,4 nmi

Scenario Values		
Today	60 s; 120 s	for heavies
(i)	50 s; 100 s	for heavies
(ii)	40 s; 80 s	for heavies

FIGURE 4-2
EFFECT OF REDUCED SEPARATIONS ON IFR AIRFIELD CAPACITY

Departure-Departure Separations. The effect of two levels of reductions in departure separations was examined. In scenario (i), separations were reduced from 1 minute to 50 seconds (2 minutes to 100 seconds behind heavies); and in scenario (ii), to 40 seconds (80 seconds behind heavies). The resulting capacity increases are shown in Figure 4-2b. As can be seen from the last graph in the figure, these departure separation reductions produce large increases in departures-only capacity. During mixed operations, these decreases allow more departures to be operated without reducing the number of arrivals; however, at 50 percent arrivals the total number of operations is constrained by the number of arrivals that can be accommodated; consequently, no increase shows in mixed operations capacity.

4.2.2 Performance Parameters

The performance parameters examined are arrival and departure ROT mean and variability, IAT variability, and length of common final approach.

Arrival Runway Occupancy Time. The effect on IFR airfield capacity of varying arrival ROT is shown in Figure 4-3a. Scenarios evaluated are the same as in VFR. The baseline case is the center bar of each graph, and represents arrival ROT of 40-50 seconds, depending upon aircraft class, with a standard deviation (s.d.) of 10 seconds for all classes. Scenarios (iii) and (iv), to the right of the baseline case, represent reductions in ROT. Again, because ROTs as low as the baseline case are not achieved at all airports, the effect of higher ROTs (scenarios (i) and (ii)) are shown to the left of the baseline.

As can be seen from the first graph in Figure 4-3a, arrival ROT is not a factor in IFR arrivals-only operations; there are no capacity gains to be had by reducing either the mean or variation. Nor are capacity increases achieved for mixed operations by reducing ROT below the baseline (today's) values. If ROTs are greater than the baseline, however, then single runway mixed operations capacity is reduced. (This is not the case for dual runways, since arrivals and departures use different runways; nor is it a factor in today's dependent parallel operations, since the 2-nmi diagonal requirement results in large separations.)

Departure Runway Occupancy Time. The effect of departure ROT on IFR airfield capacity is shown in Figure 4-3b. Scenario (i) represents a reduction in the mean and s.d. of departure ROT; scenario (ii), a reduction in the s.d. (only). As can be seen from the graphs, departure ROT is not a limiting factor in IFR for either departures-only operations or mixed operations. For departures-only operations, departure ROT rarely interferes with release of the next departure, since departure separations of 60 seconds are larger than the mean (40 seconds for large and heavy aircraft) plus 3 sigma (18 seconds). For mixed operations, departure ROT does not affect capacity due to the arrival-departure separation requirements, which is that the next arrival must be 2 nmi from the threshold in

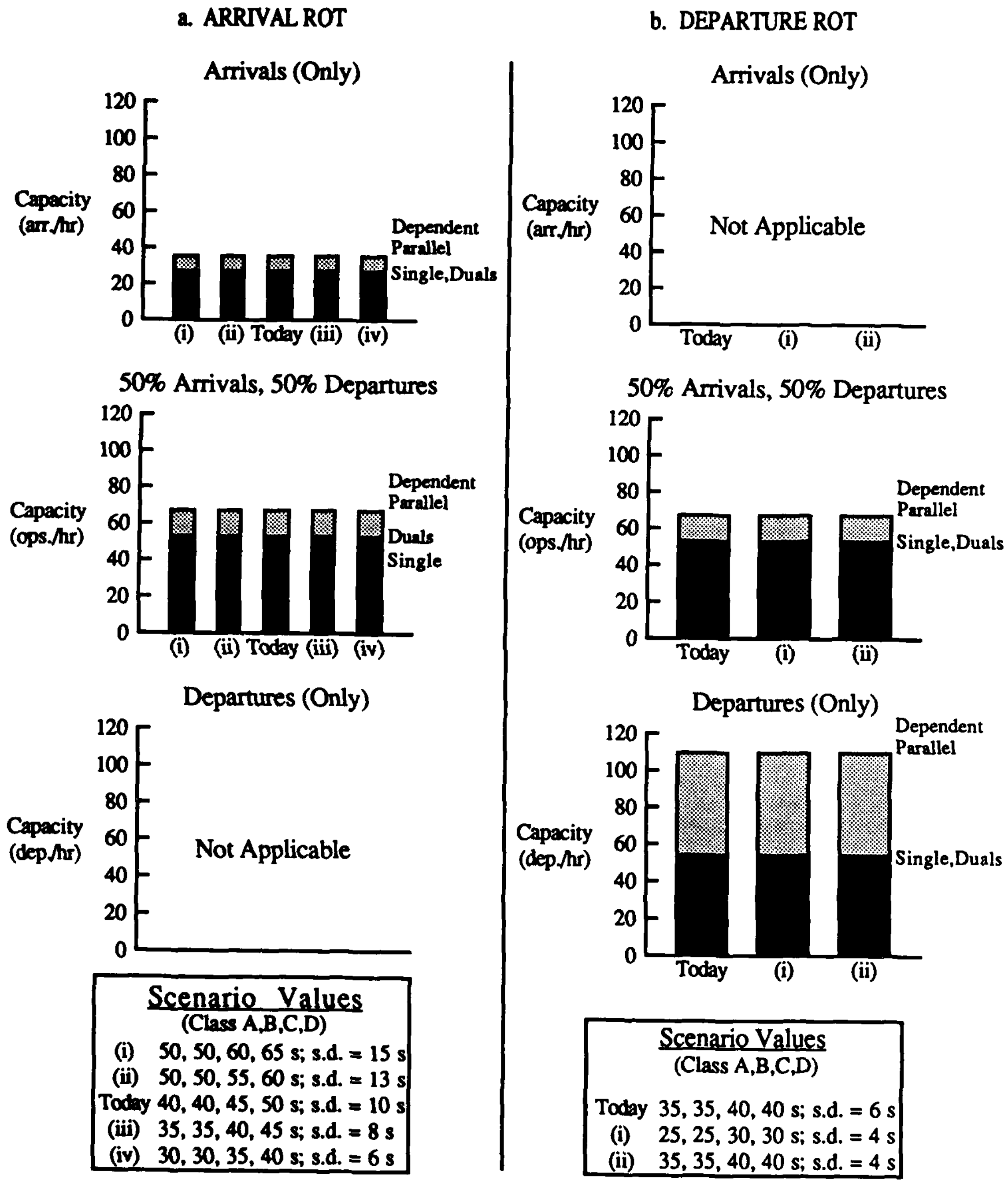


FIGURE 4-3
EFFECT OF RUNWAY OCCUPANCY TIME ON IFR AIRFIELD CAPACITY

order to release a departure; here, the critical parameter is not departure but arrival runway occupancy time, since the previous arrival must exit the runway before the departure can be released.

Interarrival Time Variability. The effect on IFR airfield capacity of reducing IAT variability by 33 percent (to 12 seconds, 1 s.d.), and by 50 percent (to 9 seconds, 1 s.d.) is shown in Figure 4-4a. The 50 percent reduction in IAT variability results in a 12 percent increase in arrivals-only capacity for single and dual runways (single arrival streams), and 16 percent for dependent parallel operations. Note the significant percentage increase for dependent parallel operations (16 percent); while one of the major limitations on dependent parallel operations is the 2-nmi diagonal separation requirement, a reduction in IAT variability can also provide a major capacity increase by reducing the additional spacing that is maintained beyond the 2-nmi diagonal.

The effect of these reductions on mixed operations is shown in the second graph of Figure 4-4a. The percentage increases are the same as for arrivals-only, except that the single runway capacity increases by only 4 percent because of ROT. Mean ROT would need to be decreased to 30, 30, 35, 40 seconds (Class A, B, C, D) to achieve the same 12 percent increase in single runway capacity that is achieved for dual runways from a 50 percent reduction in IAT variability.

Length of Common Final Approach Path. The effect of reductions in the length of the final approach path (to reduce the impact of speed differentials on capacity) is shown in Figure 4-4b. A 2-nmi reduction, from 7 to 5 nmi (scenario (i)), produces a 2-3 percent increase in arrivals-only and mixed operations capacity--an increase of only one arrival/hour for dependent parallels, and less than one arrival/hour for single and dual runways. Further reductions to 3-4 nmi (scenario (ii)) produces further small increases, except for single runway mixed operations, which are limited by ROT.

4.2.3 Summary of the Effects of Changes in Parameters

A summary of the potential increases in IFR capacity from reductions in the individual parameters is shown in Figure 4-5. The graph shows the percentage increase in capacity for each type of operation (arrivals-only, mixed operations, and departures-only) from reducing parameter values to intermediate (scenario (i)) values (except for IAT variability, which was reduced by 50 percent (scenario (ii)). Since percentage increases are fairly constant for each of the runway configurations analyzed, only one bar is shown; a percentage range indicates differences in individual configurations. For example, if the diagonal separation requirement for dependent parallels is reduced from 2 nmi to 1 nmi, then the IFR arrivals-only capacity of dependent parallels increases 25 percent; if the

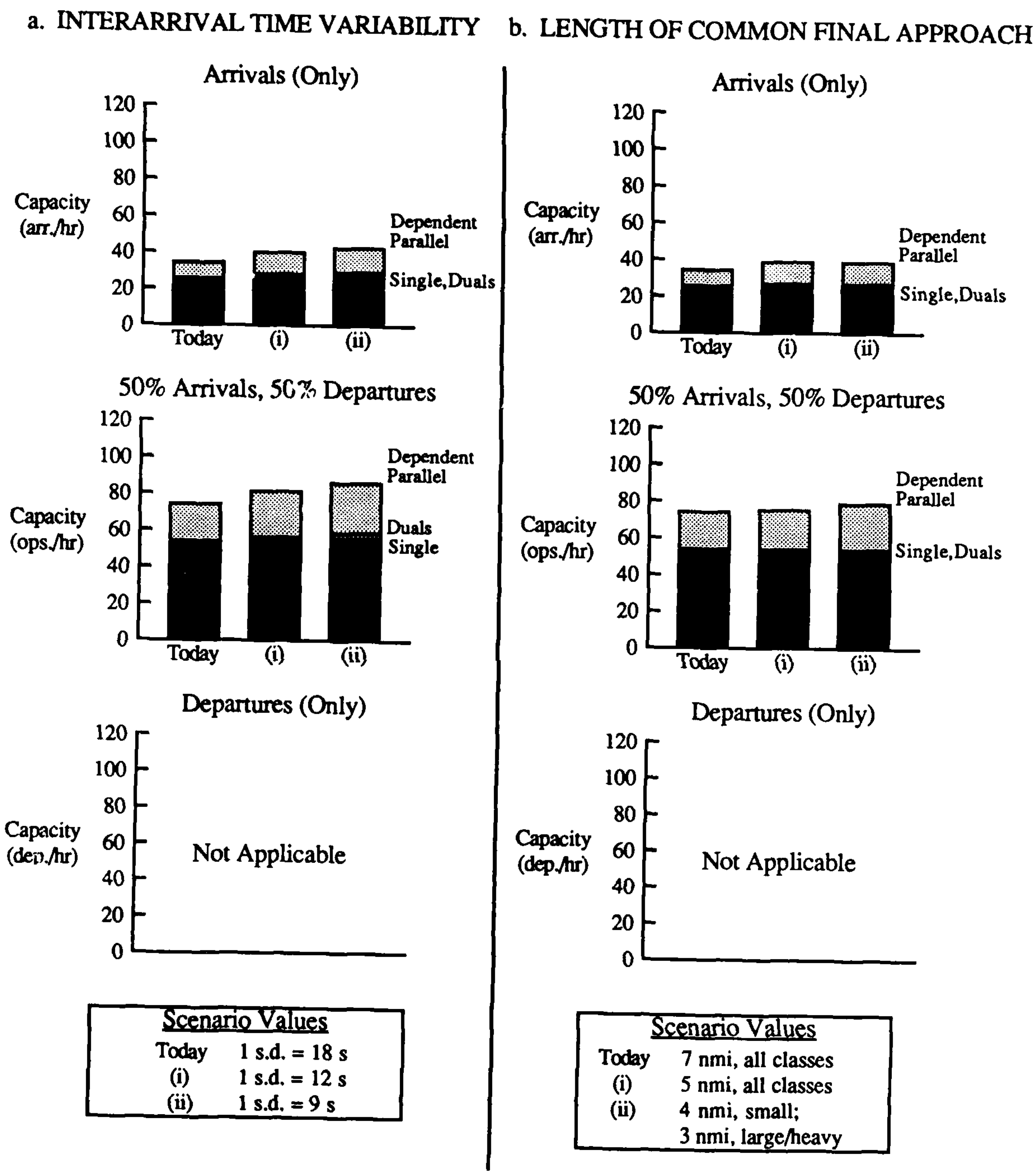


FIGURE 4-4
EFFECT OF OTHER PARAMETERS ON IFR AIRFIELD CAPACITY

a. ARRIVALS - ONLY

Parameter		Reduction From	Reduction To	Percentage Increase In IFR Capacity
Interarrival separations	Diag.[1]	2 nmi	1 nmi	25%
	Long.[2]	3-6 nmi	2 1/2-5 nmi	15%
IAT variability		18 s	9 s	12-16%
Common final		7 nmi	5 nmi	2-3%
Arrival ROT	mean	40-50 s	30-40 s	0%
	variability	10 s	5 s	0%

b. 50% ARRIVALS, 50% DEPARTURES

Parameter		Reduction From	Reduction To	Percentage Increase In IFR Capacity
Interarrival separations	Diag.[1]	2 nmi	1 nmi	25%
	Long.[2]	3-6 nmi	2 1/2-5 nmi	15%[3]
IAT variability		18 s	9 s	12-16%[3]
Common final		7 nmi	5 nmi	2-3%
Arrival ROT	mean	40-50 s	30-40 s	0%
	variability	10 s	5 s	0%
Departure ROT	mean	35-40 s	25-30 s	0%
	variability	6 s	4 s	0%

c. DEPARTURES - ONLY

Parameter		Reduction From	Reduction To	Percentage Increase In IFR Capacity
Departure separations		50-60 s (120 s / heavies)	40-50 s (100 s / heavies)	20%
Departure ROT	mean	35-40 s	25-30 s	0%
	variability	6 s	4 s	0%

1 For dependent parallels only.
2 For single & dual runways only.
3 Capacity increase limited to 3-4% for single runways due to ROT limitations.

FIGURE 4-5
INCREASES IN IFR CAPACITY FROM PARAMETER REDUCTIONS

longitudinal separation requirement is reduced from 3 to 2½ nmi (with 1-nmi reductions in the wake vortex rules), then the IFR arrivals-only capacity of single and dual runways increases 15 percent.

As can be seen from Figure 4-5, it is reduction in separation requirements that produce the greatest IFR capacity increases for any configuration and percent arrivals. The increase from IAT variability reductions, while smaller, still represents a significant area for capacity increases. Other factors produce small increases or no increases at all. ROT, which has a significant impact on VFR operations at 50 percent arrivals, has virtually no impact in IFR (it only limits potential increases from reduction in other parameters for single runway mixed operations).

Multiple Approach Concepts. An additional area for IFR arrival capacity increases is the development of multiple approach concepts. One of the major differences between VFR and IFR operations is the restrictions on the use of multiple runway configurations; technical solutions that would allow use of multiple runway configurations in IFR offer the potential for substantial increases in IFR capacity. Some examples of multiple approach concepts, along with the capacity increases they represent, are listed in Table 4-1. Increases shown in the table are for today's IFR operations; additional increases would be provided if the technical solutions described in this section were also applied.

TABLE 4-1
EXAMPLES OF POTENTIAL INCREASES IN IFR CAPACITY
FROM DEVELOPMENT OF MULTIPLE APPROACH CONCEPTS

CONCEPT	PERCENT INCREASE IN IFR CAPACITY
Independent Parallels	44% (over dependent parallels)
Independent Converging	100% (over single runway)
Triple Independent Approaches	50% (over two independent)

4.3 Overall Expectations for IFR Capacity Increases

Expectations for capacity increases in IFR depend on the changes in the parameters that are actually achieved. In this section, an estimate is made of the magnitude of capacity gains that can realistically be expected for IFR. Also included is a comparison of the potential for capacity increases through two alternative approaches.

4.3.1 Upper Bounds

Theoretical Upper Bound. An estimate of the theoretical upper bound of capacity increases in IFR was computed by setting all system variabilities (IAT and ROT) to zero, and separation rules to VFR values, approximately. As with the VFR figure, this estimate is useful for comparison only, to determine whether a given estimate of increases in IFR capacity is realistic.

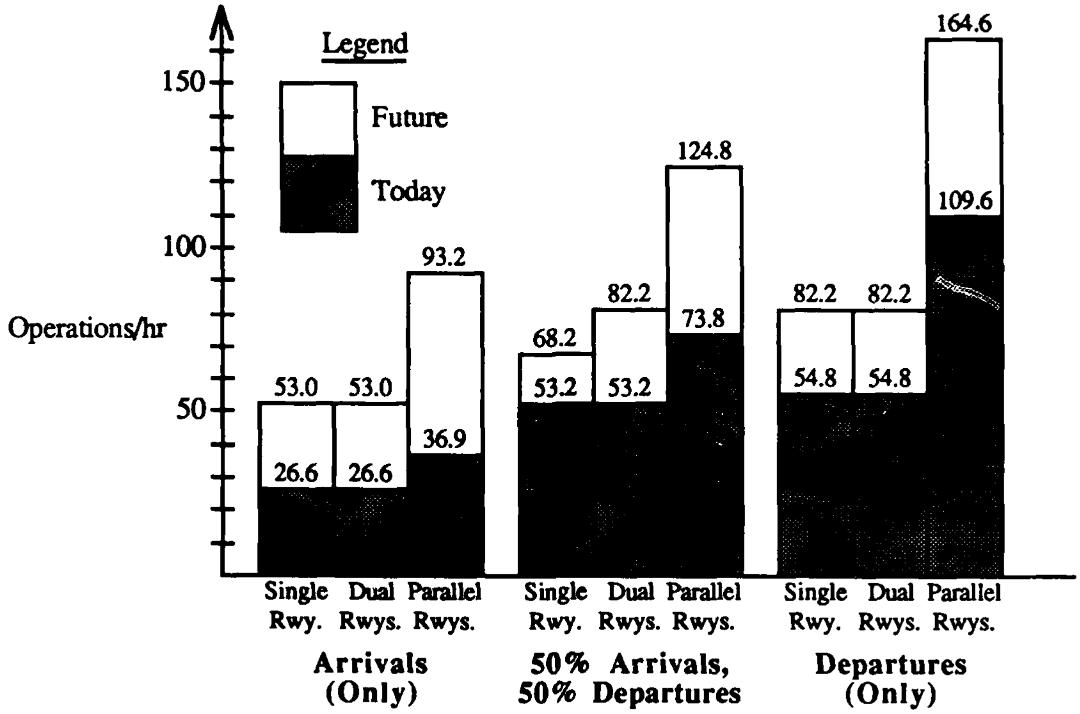
This theoretical upper bound on IFR capacity increases is shown in Figure 4-6. The parameter values this scenario is based upon are also listed in the figure. The upper bound on capacity increases ranges from 50 percent (departures-only, any runway configuration) to 153 percent (arrivals-only, dependent parallels). These represent unachievable increases.

Realistic Upper Bound. A more realistic (yet still optimistic) upper bound on expectations for increases from ATC system improvements under IFR is obtained by setting parameters to intermediate values. These values represent approximately 50 percent reductions in variabilities, and separations halfway between today's IFR and VFR values. Parameter values and the resulting capacity increases are shown in Figure 4-7. Increases range from 9 to 78 percent, depending on runway configuration and percent arrivals. In comparison, capacity increases from development of multiple approach concepts range from 44 percent (over dependent parallels) to 100 percent (over a single runway).

4.3.2 Comparison of Approaches to Achieving IFR Capacity Increases

Reducing the variability in ATC operation through the use of automation techniques is seen as a way of achieving increased airport capacity without having to resolve the safety questions and pilot acceptance issues involved in reducing separation requirements. The question then arises as to the magnitude of variability reductions necessary to achieve the same increases as reducing separations. A comparison of the IAT variability reductions necessary to achieve the same capacity increases as reductions in separation requirements, for each of the runway configurations at 50 percent arrivals, is shown in Table 4-2.

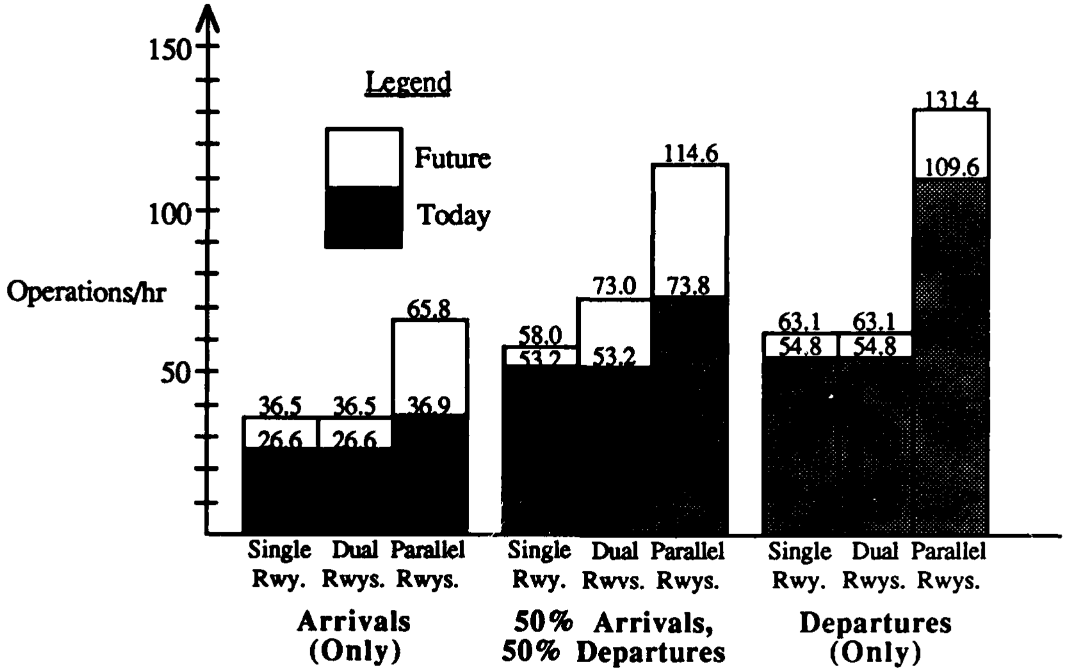
Reductions in the separation requirements for single runways, as shown in Table 4-2, produce only a small (3 percent) increase (due to ROT limitations); yet a significant reduction in IAT variability is required to achieve the same capacity increase. For dual runways, where ROT is not a factor, the separation reductions produce a 13 percent increase; IAT variability would have to be reduced by more than 50 percent to achieve the same increase. A reduction in the diagonal separation requirement for dependent parallel operations from 2 to 1 nmi produces a 25 percent



Assumed Basis for Capacity Increases

Parameter	Reduction From	Reduction To
Arrival separations	3, 4, 5, 6 nmi	2, 2 1/2, 3, 4 nmi
(diagonal for dependent parallels)	2 nmi	1/2 nmi
Departure separations	60 s (120 s for heavies)	40 s (80 s for heavies)
IAT variability (1 s.d.)	18 s	0 s
Arrival ROT -- mean (class A, B, C, D)	no change	
-- variability (1 s.d.)	10 s	0 s
Departure ROT -- mean	no change	
-- variability (1 s.d.)	6 s	0 s
Length of common final approach	7 nmi	3-4 nmi

FIGURE 4-6
THEORETICAL UPPER BOUND ON IFR CAPACITY INCREASES



Assumed Basis for Capacity Increases

Parameter	Reduction From	Reduction To
Arrival separations	3, 4, 5, 6 nmi	2 1/2, 3, 4, 5 nmi
(diagonal for dependent parallels)	2 nmi	1 nmi
Departure separations	60 s (120 s for heavies)	50 s (100 s for heavies)
IAT variability (1 s.d.)	18 s	9 s
Arrival ROT -- mean (class A, B, C, D)	no change	
-- variability (1 s.d.)	10 s	5 s
Departure ROT -- mean	no change	
-- variability (1 s.d.)	6 s	4 s
Length of common final approach	7 nmi	5 nmi

FIGURE 4-7
"REALISTIC" UPPER BOUND ON IFR CAPACITY INCREASES

TABLE 4-2
COMPARISON OF SEPARATION STANDARD AND IAT VARIABILITY REDUCTIONS ON IFR MIXED OPERATIONS CAPACITY

RUNWAY CONFIGURATION	SEPARATION REDUCTION CHANGED TO	SEPARATION REDUCTION CAPACITY		IAT VARIABILITY REDUCTION CHANGED TO	IAT VARIABILITY REDUCTION CAPACITY
Single	2½, 3, 4, 5	54.6 (3%)	=	1 s.d.=13.0 s	54.4 (2%)
Dual	2½, 3, 4, 5	60.2 (13%)	=	1 s.d.= 7.0 s	60.2 (13%)
Dependent Parallel	1 nmi Diag.	92.4 (25%)	=	1 s.d.= 4.5 s	92.8 (26%)
	Independent Operations	106.4 (44%)	>	1 s.d.= 0.0 s	100.8 (37%)

increase in capacity; it would take a 75 percent reduction in IAT variability, from 18 seconds to 4.5 seconds, to produce the same capacity increase. If the necessary procedures are developed to allow independent operations for configurations that currently must operate dependently, the result is a 44 percent increase in capacity that cannot be matched by IAT variability reductions, even to 0.0.

A reduction in ATC system variability produces a significant gain in capacity. However, achieving IAT variability reductions that produce capacity increases equivalent to separation rule reductions may prove technologically difficult.

4.4 Conclusions for IFR

Based on this analysis, the following conclusions are drawn regarding IFR capacity:

- The factors with the greatest effect in IFR capacity, as shown in Figure 4-8, are:

  1. Multiple independent approach concepts, which can produce capacity increases of 44 to 100 percent

  2. Reduction in separation requirements between approaches for multiple dependent approaches, 25 percent

  3. Reduction in longitudinal separation standards, 15 percent

  4. Reduction in system variabilities, 12-16 percent

  In IFR, it is the separation requirements that most limit capacity.

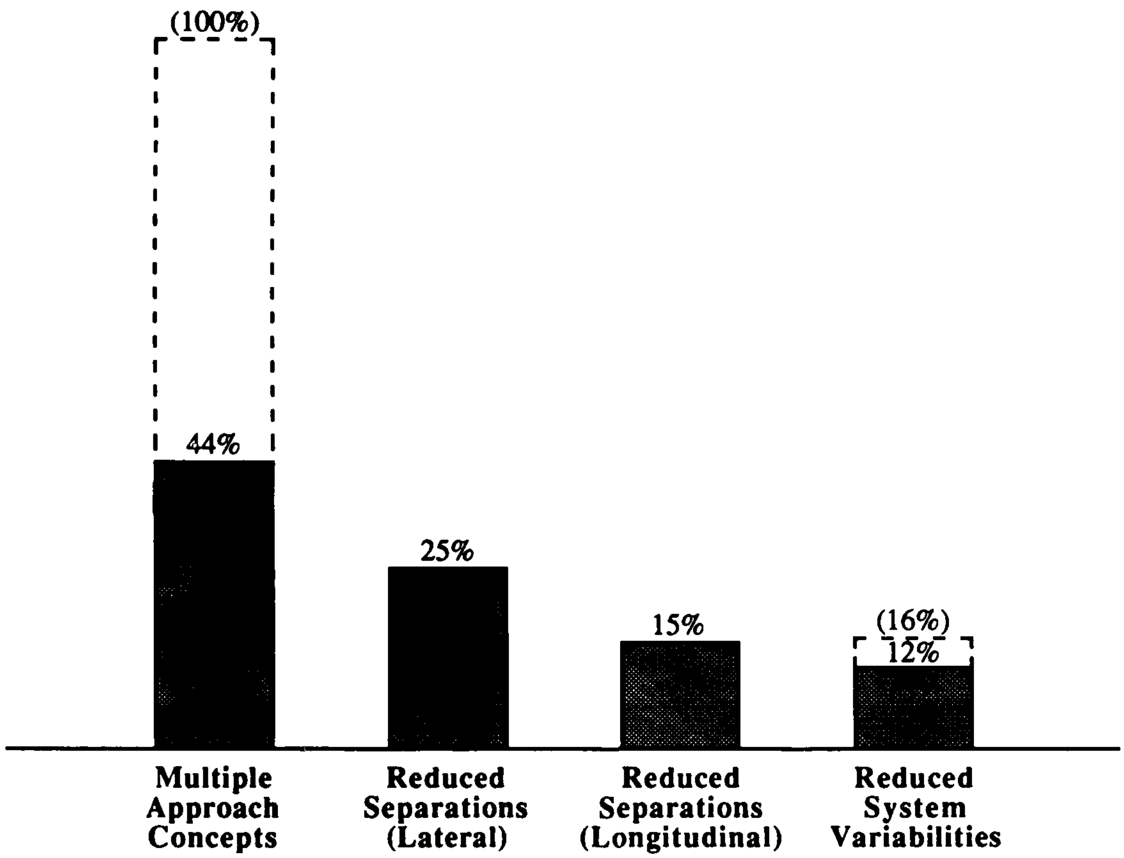


FIGURE 4-8
CAPACITY INCREASES FROM IFR CONCEPT DEVELOPMENTS

- While separation rules produce greater increases, significant capacity increases result from decreases in variability factors. The most significant of these is interarrival time variability, a 50 percent reduction in which results in a 12-16 percent capacity increase.

- Runway occupancy time, which has a major impact in VFR, is not a significant limitation in IFR and will not interfere with the capacity gains shown above. An exception is single runway mixed operations, where arrival ROT decreases are needed to support increases from reductions in other factors.

5.0 COMPARISON OF IFR AND VFR CAPACITY

One of the areas of greatest concern regarding airfield capacity is the difference in capacity between VFR and IFR operations. Given the same runway configuration and demand conditions, the IFR capacity is invariably less than the VFR capacity. Demand schedules predicated on VFR operations can result in substantial delays when weather conditions force the use of IFR operations.

5.1 Difference Between Today's VFR and IFR Capacity

The difference between today's VFR and IFR airfield capacities is the result of the more restrictive operating rules in IFR, compared with VFR. These restrictions include the following:

- Limitations on the number of runways that can be operated in any particular configuration (for example, only one of the two runways in a dual parallel configuration).

- Requirements for dependent operations (for example, the 2-nmi diagonal requirement in IFR for runways spaced 2500 to 4299 feet; these runways are independent in VFR).

- Use of IFR longitudinal separations, which, at 3 to 6 nmi, are larger than the observed VFR separations.

- Use of 1-minute departure separations, which can be 10 to 20 seconds longer than observed VFR departure separations.

The magnitude of the difference between the VFR and IFR capacities varies considerably. For the runway configurations and demand conditions analyzed in this study, Table 5-1 shows the VFR and IFR capacities and the reduction, in terms of both operations and percentage, that occurs in the transition from VFR to IFR operations. (The transition is not instantaneous, but rather a gradual change; for example, at specific ceilings and visibilities, the ability to use certain runway configurations is lost.) The magnitudes of the reduction varies, from 5 percent (single or dependent parallel runways, departures-only) to 62 percent (dual runways, arrivals-only), and are attributable to a variety of causes. The dual runways (spacing 700 to 2499 feet) represent the greatest reductions, at 51 to 62 percent due primarily to the fact that ATC rules allow two arrival and departures streams under VFR but only one under IFR. The arrivals-only capacity of duals is further reduced due to use of IFR longitudinal separation rules.

IFR dependent parallel runway arrivals-only capacity is significantly reduced due to the requirement for dependent operations with a 2-nmi diagonal separation (vs. fully independent operations in VFR with

TABLE 5-1
COMPARISON OF TODAY'S VFR AND IFR AIRFIELD CAPACITIES

RUNWAY CONFIGURATION	TYPE OF OPERATION								
	Arrivals-Only			50% Arrivals, 50% Departures			Departures-Only		
	VFR (aircraft/hr)	IFR (aircraft/hr)	Difference (percent)	VFR (aircraft/hr)	IFR (aircraft/hr)	Difference (percent)	VFR (aircraft/hr)	IFR (aircraft/hr)	Difference (percent)
Single	36.6	26.6	10.0 (-27%)	59.8	53.2	6.6 (-11%)	57.9	54.8	3.1 (- 5%)
Dual	70.6	26.6	44.0 (-62%)	113.4	53.2	60.2 (-53%)	111.9	54.8	57.1 (-51%)
Dependent Parallel	73.2	36.9	36.3 (-50%)	119.6	73.8	45.8 (-38%)	115.9	109.6	6.3 (- 5%)

substantially smaller separations). This restriction also affects mixed operations, which, at 50 percent arrivals, are limited by the number of arrivals that can be accommodated. Since departures can be operated independently at this runway spacing, the difference in departures is relatively small (5 percent), and is attributable to the use of larger departure separations (60 seconds vs. 30-50 seconds in VFR).

The single runway arrivals-only difference of 27 percent is due primarily to the use of IFR longitudinal separations. The mixed-operations capacity difference is only 11 percent, because while in IFR the total is limited by the number of arrivals, in VFR the total is limited by runway occupancy time. The difference in departure capacity for single runways is small.

5.2 Potential for Reduction in the Difference Between VFR and IFR Capacity

To provide an indication of how the difference between VFR and IFR capacity might change, a comparison was done of the effects of the individual reductions in the parameters in VFR (from Section 3) with that in IFR (Section 4). By comparing the effects of reductions, parameter by parameter, those parameters that offer the greatest potential to reduce the difference can be identified. These parameters will manifest themselves by resulting in larger increases in IFR capacity than in VFR capacity. Conversely, if the percentage increase from any parameter is the same or larger in VFR, then the difference in capacity between VFR and IFR may increase.

A summary of the expected capacity increases from reductions in individual parameters, for VFR and IFR, is shown in Table 5-2. One parameter which shows differences in its effects in VFR and in IFR is arrival separations. In IFR, reduced separations offer potential increases of 15 to 25 percent; in VFR, potential increases are limited to 7 percent, and only for an arrivals-only operation.

For departure operations, the only parameter that can provide an increase in either VFR or IFR is departure separations, where the increase in IFR is only slightly larger than that in VFR. However, for any configuration that allows the same number of departure streams in IFR that are allowed in VFR (single runway or parallel runways spaced more than 2500 feet), the difference between the IFR and VFR departures-only capacity is only 5 percent.

Factors such as IAT variability, length of common final, and ROT will not decrease the difference between VFR and IFR capacity under most circumstances. With the exception of mixed operations, decreases in these parameters offer the equivalent or larger potential increases in VFR capacity than under IFR; consequently, achieving the same reductions in both VFR and IFR would widen the difference.

TABLE 5-2
EXPECTED CAPACITY INCREASES FROM PARAMETER REDUCTIONS IN VFR AND IFR

a. FOR VFR OPERATIONS

Parameter / Type of Operation	Arrival Separations		Departure Separations	Interarrival Time Variability	Common Approach Path	Arrival ROT	Departure ROT
	Diagonal Separations	Longitudinal Separations					
Degree of Reduction	N/A	1.9 nmi → 1.7 nmi 2.7–4.5 → 2.4–4.0	10–20 s	18 s → 9 s	3–5 nmi → 2–3 nmi	10 s	10 s
Arrivals Only		7%		17–18%	2–3%	*	
50% Arrivals, 50% Departure		**	3%	**	**	8–9%	4%
Departures Only			18%				*

b. FOR IFR OPERATIONS

Parameter / Type of Operation	Arrival Separations		Departure Separations	Interarrival Time Variability	Common Approach Path	Arrival ROT	Departure ROT
	Diagonal (Dependent Parallel)	Longitudinal (Single, Dual Rwys)					
Degree of Reduction	2 nmi → 1 nmi	3 nmi → 2.5 nmi 4–6 nmi → 3–5 nmi	10–20 s	18 s → 9 s	7 nmi → 5 nmi	10 s	10 s
Arrivals Only	25%	15%		12–16%	2–3%	*	
50% Arrivals, 50% Departure	25%	15%***	*	12–16%***	2–3%	*	*
Departures Only			20%				*

*No measurable impact under assumed baseline.
**No measurable impact without ROT reductions.
***Requires 10-second reduction in arrival ROT for single runway operation.

In addition to the factors identified in Table 5-2, one additional area to decrease the VFR/IFR capacity difference is the multiple approach concepts. As noted in Section 5.1, one of the factors that is a major contributor to reducing IFR capacity is the limitation on the use of multiple runways. The 44 to 100 percent increases in IFR capacity that can result from the development of IFR multiple approach concepts, in addition to being a significant increase in capacity, offers the best potential to reduce the difference between the IFR and VFR capacity of many runway configurations.

In summary, then, the best means to achieve a reduction in the difference between IFR and VFR capacity is through development of multiple approach concepts that allow the same number of arrival and departure streams to be operated in IFR that are allowed in VFR, and through reductions in separation rules on approach.

6.0 CONCLUSIONS

This study focuses on the capacity increases that can result from technical improvements to the ATC system, using the existing runways. Realistic upper limits on such increases are from 15 to 26 percent in VFR (depending on runway configuration and percent arrivals), and from 9 to 78 percent in IFR. In comparison, the addition of a new runway that allows an additional independent arrival and/or departure stream results in a 33 to 100 percent capacity increase (depending on whether the baseline is a single, dual, or triple runway configuration). In VFR, this would require the construction of a new runway; in IFR, increases can also come through the development of multiple approach concepts, which can result in 44 to 100 percent increases in IFR capacity (depending upon whether the baseline is a single runway, two dependent, or two independent runways). The greatest capacity increases thus come from the addition of a new runway, properly spaced to allow an additional independent arrival and/or departure stream.

While the capacity increase from technical ATC system improvements are not as large as those from the addition of new runways, they still represent a significant capacity gain. In addition, technical ATC system improvements that would allow operation of multiple independent IFR approach streams that are currently prohibited or operated only at very high weather minimums--such as converging and triple IFR approaches--would result in a significant decrease in the difference between the IFR and VFR capacities of particular runway configurations. The parameters that technical solutions must improve to provide the greatest increases in capacity vary as a function of percent arrivals, runway configuration, and weather conditions (VFR and IFR).

6.1 VFR Capacity

VFR operations today are characterized by pilot-maintained visual separations; it is not clear whether these can be reduced significantly over the long term. There are, however, limitations in the ability of the controllers and pilots to achieve these levels consistently. In addition, runway occupancy is a limitation, especially where arrivals and departures use the same runway(s). There is, therefore, room to achieve some increases in VFR capacity through technical solutions that affect these factors. The parameters that have the greatest effect and the magnitude of the expected increases from reducing those parameters are:

1. Arrivals-only capacity, 17-18 percent by reducing interarrival time variability by 50 percent.

2. Departures-only capacity, 18 percent by reducing departure separations 14 to 20 percent.

3. Mixed operations, 8-9 percent by reducing mean arrival ROT 11 to 17 percent.

6.2 IFR Capacity

IFR operations, as distinguished from VFR, are characterized by relatively large controller-maintained radar separations and procedures for avoiding collisions and wake vortices. Not only are there significantly larger separations under IFR for individual arrival streams, but also restrictions on the use of multiple arrival streams. Consequently, the biggest impacts on IFR capacity will be from increasing the ability to operate multiple arrival streams.

The technical solutions that provide the greatest impact on IFR capacity are as follows:

1. Multiple independent approach concepts, where applicable, which can increase capacity 44 to 100 percent over the previous "best" capacity.

2. Reductions in the separation requirements between multiple dependent approaches, which can increase capacity by 25 percent.

3. Reductions in the longitudinal separation standards, which can increase capacity 15 percent.

4. Reduction in system variabilities, which can increase capacity by 12-16 percent.

APPENDIX A

VFR AIRFIELD CAPACITY COMPUTATIONS

This appendix provides a detailed description of the parameter values and results of the computation process for VFR capacity. A complete list of parameters is provided for each scenario analyzed in this study, followed by tables showing the results of the computation using the FAA Airfield Capacity Model.

The performance parameters and separation values used in the computations are taken from Reference 4, with the exception of the baseline runway occupancy times, which are taken from reports of the reduced longitudinal separation analyses (References 6 and 7). In many cases, the parameters vary by aircraft class. Four aircraft classes were assumed for the model, as listed in Table 2-1 (which is reprinted here as Table A-1). In this analysis, when referring to aircraft "class" it is the model class that is meant.

TABLE A-1
AIRCRAFT CLASSIFICATIONS

MODEL CLASS	AIRCRAFT TYPE	WAKE VORTEX CLASS	FINAL APPROACH SPEED
A	Small Aircraft	I Small	100 Kts
B	Large Prop	II Large	110 Kts
C	Large Jet	II Large	130 Kts
D	Heavy Jet	III Heavy	140 Kts

A.1 Todays VFR Capacity

The parameter values representing today's VFR operations are summarized in Table A-2. In VFR, there is no formal set of separation standards that are applied to aircraft. Rather, the lead aircraft is pointed out to the pilot of the trailing aircraft who maintains separation from that aircraft by visual means. Actual separations thus vary at the pilot's discretion. The observed arrival-arrival separations listed in Table A-2 are values such that 95 percent of aircraft pairs are observed to have this separation or larger; this representation is chosen since the model works on an assumed "minimum" separation that is violated 5 percent of the time.

TABLE A-2
PARAMETERS USED IN COMPUTATION OF TODAY'S VFR CAPACITY

PARAMETER	AIRCRAFT CLASS A	B	C	D
Arrival Separations, nmi				
Behind Heavies	4.5	3.6	3.6	2.7
Behind All Others	2.7*	1.9	1.9	1.9
Departure Separations, s				
Behind Heavies (D)	120	120	120	90
Behind Large (B,C)	50	60	60	60
Behind Small (A)	35	45	45	50
Arrival ROT, s				
Mean	40	40	45	50
Standard Deviation	10	10	10	10
Departure ROT, s				
Mean	35	35	40	40
Standard Deviation	6	6	6	6
IAT Variability, s	18	18	18	18
Length of Final Approach, nmi	3	3	5	5

*1.9 for class A behind class A.

Departure separations between aircraft class-pairs are observed separations. The exception is when a "heavy" aircraft is the lead aircraft; under these circumstances, larger separations are provided for wake vortex protection: A heavy following a heavy is required to be separated by 90 seconds; any other aircraft, by two minutes.

Arrival ROT varies from airport to airport, depending on exit location and type of aircraft, and can even vary by airline (as a function of where the aircraft's gate is located). Selection of particular values for use in this analysis is based on the runway occupancy times observed for airports participating in the reduced longitudinal separation demonstration. While these are lower than those observed at many airports, they represent values that are achievable today. Departure ROT, on the other hand, is quite consistent from airport to airport.

The IAT variability of 18 seconds is a 1 standard deviation value. The model assumes that a distance separation corresponding to 1.65 times this time value is added beyond the "minimum" separations. Finally, the length of the common final approach path shown in Table A-1 is consistent with today's air traffic control practices in which smaller, slower aircraft are merged into the arrival stream closer to the threshold.

These inputs, used in the FAA airfield capacity model, produce the results shown in Table A-3 (and Figure 3-1).

TABLE A-3
TODAY'S VFR CAPACITY

RUNWAY CONFIGURATION	TYPE OF OPERATION		
	ARRIVALS (ONLY)	DEPARTURES (ONLY)	50% ARRIVALS, 50% DEPARTURES
Single	36.6	57.9	59.8
Dual (700-2499 ft)	70.6	111.9	113.4
Parallel (2500-4299 ft)	73.2	115.9	119.6

A. 2 Effect on VFR Capacity of Variations in Parameters

Table A-4 lists the parameter values changed and the capacity computation results shown in the graphs in Section 3.2 (Figures 3-2 through 3-4). The first column lists the parameter changed. The second column lists the scenario that particular row represents ("T" means today; other scenarios are identified by a lower case roman numeral); this is followed by parameter values for that scenario, for each aircraft class, in rows 3-6. The last 9 rows are the capacities for the three runway configurations for arrival-only, mixed, and departure-only operations.

A.3 Computation of Upper Bounds on VFR Capacity

Theoretical Upper Bound. The parameters used in computing the theoretical upper bound on VFR capacity shown in Figure 3-6 are listed in Table A-5. The scenario uses today's arrival separations and mean runway occupancy times; all other parameters represent reductions to absolute minimums (0.0 for variabilities, nominal amounts for other parameters). Results of the computation are shown in Table A-6.

PARAMETER CHANGED						CAPACITY					
		VALUE				ARRIVAL-ONLY			50% ARRIVALS, 50% DEPARTURES		
Parameter	Scenario	A	B	C	D	Single	Duals	Parallels	Single	Duals	Parallels
Arrival Separations (nmi)	T	4.5 2.7	3.6 1.9	3.6 1.9	2.7 1.9	36.6	70.6	73.2	59.8	113.4	119.6
(Figure 3-2a)	(i)	4.0 2.4	3.2 1.7	3.2 1.7	2.4 1.7	39.0	75.2	78.0	59.8	113.4	119.6
	(ii)	3.0 2.0	2.5 1.5	2.5 1.5	2.0 1.5	41.5	80.4	83.0	59.8	113.4	119.6
Departure Separations (s) (Figure 3-2b)	T	120 50 35	120 60 45	120 60 45	90 60 50	36.6	70.6	73.2	53.2	53.2	73.8
	(i)	100 45 30	100 50 40	100 50 40	80 50 45	36.6	70.6	73.2	61.4	117.0	122.8
	(ii)	80 35 25	80 40 30	80 40 30	60 40 35	36.6	70.6	73.2	64.2	122.4	128.4
Arrival ROT (s) (Figure 3-3a)	(i)	μ 50 σ 15	50 15	60 15	65 15	33.8	65.5	67.6	53.4	102.8	106.8
	(ii)	μ 50 σ 13	50 13	55 13	60 13	35.1	67.7	70.2	54.8	105.2	109.6
	T	μ 40 σ 10	40 10	45 10	50 10	36.6	70.6	73.2	59.8	113.4	119.6
	(iii)	μ 35 σ 8	35 8	40 8	45 8	36.7	70.6	73.4	62.6	118.0	125.2
	(iv)	μ 30 σ 6	30 6	35 6	40 6	36.7	70.6	73.4	65.4	122.6	130.8
Departure ROT (s) (Figure 3-3b)	T	μ 35 σ 6	35 6	40 6	40 6	36.6	70.6	73.2	59.8	113.4	119.6
	(i)	μ 25 σ 4	25 4	30 4	30 4	36.6	70.6	73.2	67.0	125.6	134.0
	(ii)	μ 35 σ 4	35 4	40 4	40 4	36.6	70.6	73.2	61.6	116.4	123.2
Interarrival Time	T	18	18	18	18	36.6	70.6	73.2	59.8	113.4	119.6
Variability (s)	(i)	12	12	12	12	40.7	78.1	81.4	59.8	113.4	119.6
(Figure 3-4a)	(ii)	9	9	9	9	43.1	82.4	86.2	59.8	113.4	119.6
Length of Common	T	3	3	5	5	36.6	70.6	73.2	59.8	113.4	119.6
Final Approach (nmi)	(i)	2	2	3	3	37.6	71.9	75.2	59.8	113.8	119.6
(Figure 3-4b)	(ii)	1	1	1	1	38.2	73.3	76.4	59.8	113.8	119.6

DEPARTURE-ONLY		
ingle	Duals	Parallels
57.9	111.9	115.9
57.9	111.9	115.9
57.9	111.9	115.9
54.8	54.8	109.6
68.3	132.3	136.6
83.9	162.7	167.8
57.9	111.9	115.9
57.9	111.9	115.9
57.9	111.9	115.9
57.9	111.9	115.9
57.9	111.9	115.9
57.9	111.9	115.9
57.9	111.9	115.9
57.9	111.9	115.9
57.9	111.9	115.9
57.9	111.9	115.9
57.9	111.9	115.9
57.9	111.9	115.9
57.9	111.9	115.9
57.9	111.9	115.9

TABLE A-4
VFR CAPACITY COMPUTATION RESULTS

TABLE A-5
PARAMETERS USED FOR COMPUTATION OF THEORETICAL UPPER BOUND

PARAMETER	AIRCRAFT CLASS A	B	C	D
Arrival Separations, nmi				
Behind Heavies	4.5	3.6	3.6	2.7
Behind All Others	2.7*	1.9	1.9	1.9
Departure Separations, s				
Behind Heavies (D)	100	100	100	80
Behind Large (B,C)	40	50	50	50
Behind Small (A)	30	40	40	45
Arrival ROT, s				
Mean	40	40	45	50
Standard Deviation	0.0	0.0	0.0	0.0
Departure ROT, s				
Mean	35	35	40	40
Standard Deviation	0.0	0.0	0.0	0.0
IAT Variability, s	0.0	0.0	0.0	0.0
Length of Final Approach, nmi	2	2	3	3

*1.9 for class A behind class A.

TABLE A-6
THEORETICAL UPPER BOUND OF VFR CAPACITY INCREASES

RUNWAY CONFIGURATION	TYPE OF OPERATION: ARRIVALS (ONLY)	DEPARTURES (ONLY)	50% ARRIVALS, 50% DEPARTURES
Single	53.6 (46%)	68.5 (18%)	59.8 (0%)
Dual (700-2499 ft)	101.9 (44%)	132.5 (18%)	113.4 (0%)
Parallel (>2500 ft)	107.2 (46%)	137.0 (18%)	119.6 (0%)

Since no capacity increases result for mixed operations unless ROT is reduced, the computation was redone, reducing ROT in 5-second increments until ROT is no longer a factor. This occurs at mean arrival ROT of 15, 15, 20, 25 seconds (class A, B, C, D), and produces the capacity increases shown in Table A-7.

TABLE A-7
THEORETICAL UPPER BOUND OF VFR CAPACITY INCREASES FOR MIXED OPERATIONS WITH REDUCED RUNWAY OCCUPANCY TIME

RUNWAY CONFIGURATION	TYPE OF OPERATION 50% ARRIVALS, 50% DEPARTURES
Single	107.2 (79%)
Dual (700-2499 ft)	195.2 (72%)
Parallel (>2500 ft)	214.4 (79%)

"Realistic" Upper Bound. Parameter values used in the computation of the "realistic" upper bound of capacity increases shown in Figure 3-7 are listed in Table A-8. Arrival separation values are today's; all other parameter reductions represent nominal reductions, as follows: IAT and ROT variabilities are reduced 50 percent from today's values; mean arrival and departure ROTs are reduced 5 seconds (otherwise, no mixed operations capacity increases are possible); all other parameters to the values listed in the table. Table A-9 shows the results of the computation using these values.

TABLE A-8
PARAMETERS USED IN COMPUTATION
OF "REALISTIC" UPPER BOUND

PARAMETER	AIRCRAFT CLASS A	B	C	D
Arrival Separations, nmi				
Behind Heavies	4.5	3.6	3.6	2.7
Behind All Others	2.7*	1.9	1.9	1.9
Departure Separations, s				
Behind Heavies (D)	100	100	100	80
Behind Large (B,C)	40	50	50	50
Behind Small (A)	30	40	40	45
Arrival ROT, s				
Mean	35	35	40	45
Standard Deviation	5	5	5	5
Departure ROT, s				
Mean	30	30	35	35
Standard Deviation	3	3	3	3
IAT Variability, s	9	9	9	9
Length of Final Approach, nmi	2	2	3	3

*1.9 for class A behind class A.

TABLE A-9
ESTIMATE OF "REALISTIC" UPPER BOUND
OF CAPACITY INCREASES IN VFR

RUNWAY CONFIGURATION	TYPE OF OPERATION ARRIVALS (ONLY)	DEPARTURES (ONLY)	50% ARRIVALS, 50% DEPARTURES
Single	44.0 (20%)	68.5 (18%)	73.2 (22%)
Dual (700-2499 ft)	84.4 (20%)	132.5 (18%)	138.2 (22%)
Parallel (>2500 ft)	88.0 (20%)	137.0 (18%)	146.4 (22%)

APPENDIX B

IFR AIRFIELD CAPACITY COMPUTATIONS

This appendix provides a detailed description of the parameter values and results of the computation process for IFR capacity. A complete list of parameters is provided for each scenario analyzed in this study, followed by tables showing the results of the computation from the FAA Airfield Capacity Model.

The performance parameters and separation values used in the computations are taken from Reference 4, with the exception of the baseline runway occupancy times, which are taken from reports of the reduced longitudinal separation analyses (References 6 and 7). In many cases, the parameters vary by aircraft class. Four aircraft classes were assumed for the model, as listed in Table 2-1 (which is reprinted here as Table B-1). In this analysis, when referring to aircraft "class" it is the model class that is meant.

TABLE B-1
AIRCRAFT CLASSIFICATIONS

MODEL CLASS	AIRCRAFT TYPE	WAKE VORTEX CLASS	FINAL APPROACH SPEED
A	Small Aircraft	I Small	100 Kts
B	Large Prop	II Large	110 Kts
C	Large Jet	II Large	130 Kts
D	Heavy Jet	III Heavy	140 Kts

B.1 Todays IFR Capacity

The parameter values representing today's IFR operations are summarized in Table B-2. In IFR, radar separation rules are assumed to apply over the entire final approach path. These rules include longitudinal separation rules, for aircraft approaching the same runway, and lateral rules, for dependent operations tc different runways. Three nmi in-trail is required as a minimum radar separation between arrivals on final approach*. Other separations listed in the table that

*Except under a program in which longitudinal spacing may be reduced to 2½ nmi under specific conditions (including reduced arrival ROT.

are larger than 3 nmi are for wake vortex separation purposes. In addition, for dependent parallel operations (runways spaced 2500 to less than 4300 ft.), there is an additional requirement for 2-nmi diagonal spacing between aircraft on adjacent approaches. The basic IFR departure separation requirement is 1 minute between departures. Again, when following a heavy aircraft, another heavy must be separated by 90 seconds; any other aircraft, by 2 minutes. There are no additional requirements between aircraft departing different runways; any runways spaced 2500 feet or more may be operated independently.

TABLE B-2
PARAMETERS USED IN BASELINE CASE

PARAMETER	AIRCRAFT CLASS			
	A	B	C	D
Arrival Separations, nmi				
Behind Heavies	6.0	5.0	5.0	4.0
Behind All Others	4.0*	3.0	3.0	3.0
Departure Separations, s				
Behind Heavies (D)	120	120	120	90
Behind All Others (A,B,C)	60	60	60	60
Arrival ROT, s				
Mean	40	40	45	50
Standard Deviation	10	10	10	10
Departure ROT, s				
Mean	35	35	40	40
Standard Deviation	6	6	6	6
IAT Variability, s	18	18	18	18
Length of Final Approach, nmi	7	7	7	7

*3.0 for class A behind class A.

Performance parameters are the same values in IFR as in VFR with the exception of length of common final approach. Again, selection of particular arrival ROT values for use in this analysis is based on ROTs observed for airports participating in the reduced longitudinal separation demonstration. While these are lower than those observed at many airports, they represent values that are achievable today. The 7-nmi length of final approach assumes all aircraft follow an instrument approach, with aircraft being lined up on the localizer 2 nmi prior to the outer marker, which is typically 5 nmi from threshold.

Computation Results. These inputs, used in the FAA airfield capacity model, produce the results shown in Table B-3 (and Figure 4-1).

TABLE B-3
TODAY'S IFR CAPACITY

	TYPE OF OPERATION		
RUNWAY CONFIGURATION	ARRIVALS (ONLY)	DEPARTURES (ONLY)	50% ARRIVALS, 50% DEPARTURES
Single	26.6	54.8	53.2
Dual (700-2499 ft)	26.6	54.8	53.2
Parallel (2500-4299 ft)	36.9	109.6	73.8

B. 2 Effect on IFR Capacity of Variations in Parameters

Table B-4 lists the parameter values changed and the capacity computation results shown in the graphs in Section 4.2 (Figures 4-2 through 4-4). The first column lists the parameter changed. The second column lists the scenario that particular row represents ("T" means today; other scenarios are identified by a lower case roman numeral); this is followed by parameter values for that scenario, for each aircraft class, in rows 3-6. The last 9 rows are the capacities for the three runway configurations for arrivals-only, mixed, and departures-only operations.

PARAMETER CHANGED						CAPACITY					
		VALUE				ARRIVAL-ONLY			50% ARRIVALS, 50% DEPARTURES		
Parameter	Scenario	A	B	C	D	Single	Duals	Dependent Parallels	Single	Duals	Dependent Parallels
Arrival Separations (nmi)	T	6.0 4.0	5.0 3.0	5.0 3.0	4.0 3.0	26.6	26.6	36.9	53.2	53.2	73.8
(Figure 4-3a)	(i)	5.0 3.0	4.0 2.5	4.0 2.5	3.0 2.5	30.7	30.7	37.2	54.6	60.2	74.4
	(ii)	4.0 2.5	3.0 2.0	3.0 2.0	2.5 2.0	35.6	35.6	37.3	54.6	69.4	74.6
With 1-nmi Diagonal	T							46.2			92.4
Separation	(i)							51.0			102.0
	(ii)							53.8			107.6
Departure Separations (nmi)	T	120 60	120 60	120 60	90 60	26.6	26.6	36.9	53.2	53.2	73.8
(Figure 4-3b)	(i)	100 50	100 50	100 50	80 50	26.6	26.6	36.9	53.2	53.2	73.8
	(ii)	80 40	80 40	80 40	60 40	26.6	26.6	36.9	53.2	53.2	73.8
Arrival ROT (s) (Figure 4-4a)	(i)	μ 50 σ 15	50 15	60 15	65 15	26.6	26.6	36.9	48.8	53.2	73.8
	(ii)	μ 50 σ 13	50 13	55 13	60 13	26.6	26.6	36.9	50.2	53.2	73.8
	T	μ 40 σ 10	40 10	45 10	50 10	26.6	26.6	36.9	53.2	53.2	73.8
	(iii)	μ 35 σ 8	35 8	40 8	45 8	26.6	26.6	36.9	53.2	53.2	73.8
	(iv)	μ 30 σ 6	30 6	35 6	40 6	26.6	26.6	36.9	53.2	53.2	73.8
Departure ROT (s) (Figure 4-4b)	T	μ 35 σ 6	35 6	40 6	40 6	26.6	26.6	36.9	53.2	53.2	73.8
	(i)	μ 25 σ 4	25 4	30 4	30 4	26.6	26.6	36.9	53.2	53.2	73.8
	(ii)	μ 35 σ 4	35 4	40 4	40 4	26.6	26.6	36.9	53.2	53.2	73.8
Interarrival Time	T	18	18	18	18	26.6	26.6	36.9	53.2	53.2	73.8
Variability (s)	(i)	12	12	12	12	28.7	28.7	40.7	54.8	54.8	81.4
(Figure 4-5a)	(ii)	9	9	9	9	29.9	29.9	42.9	55.2	55.2	85.6
Length of Common	T	7	7	7	7	26.6	26.6	36.9	53.2	53.2	[illegible]
Final Approach (nmi)	(i)	5	5	5	5	27.1	27.1	38.0	54.2	54.2	[illegible]
(Figure 4-5b)	(ii)	4	4	3	3	27.4	27.4	39.3	54.4	54.4	[illegible]

ACITY				
. 50% DEPARTURES		DEPARTURE-ONLY		
uals	Dependent Parallels	Single	Duals	Parallels
53.2	73.8	54.8	54.8	109.6
60.2	74.4	54.8	54.8	109.6
69.4	74.6	54.8	54.8	109.6
	92.4			109.6
	102.0			109.6
	107.6			109.6
53.2	73.8	54.8	54.8	109.6
53.2	73.8	65.7	65.7	131.4
53.2	73.8	82.2	82.2	164.4
53.2	73.8	54.8	54.8	109.6
53.2	73.8	54.8	54.8	109.6
53.2	73.8	54.8	54.8	109.6
53.2	73.8	54.8	54.8	109.6
53.2	73.8	54.8	54.8	109.6
53.2	73.8	54.8	54.8	109.6
53.2	73.8	54.8	54.8	109.6
53.2	73.8	54.8	54.8	109.6
53.2	73.8	54.8	54.8	109.6
54.8	81.4	54.8	54.8	109.6
55.2	85.8	54.8	54.8	109.6
53.2	73.8	54.8	54.8	109.6
54.2	76.0	54.8	54.8	109.6
54.4	78.6	54.8	54.8	109.6

TABLE B-4
IFR CAPACITY COMPUTATION RESULTS

B.3 Computation of Upper Bounds on IFR Capacity

Theoretical Upper Bound. The parameters used in computing the theoretical upper bound on IFR capacity shown in Figure 4-6 are listed in Table B-5. The scenario uses today's mean runway occupancy times; all other parameters represent reductions to absolute minimums (0.0 for variabilities, nominal amounts for other parameters). A ½-nmi diagonal separation ("don't-pass rule") was used for dependent parallel operations. Results of the computation are shown in Table B-6.

TABLE B-5
PARAMETERS USED FOR COMPUTATION OF THEORETICAL UPPER BOUND

PARAMETER	AIRCRAFT CLASS			
	A	B	C	D
Arrival Separations, nmi				
Behind Heavies	4.0	3.0	3.0	2.5
Behind All Others	2.5*	2.0	2.0	2.0
Departure Separations, s				
Behind Heavies (D)	80	80	80	60
Behind All Others (A,B,C)	40	40	40	40
Arrival ROT, s				
Mean	40	40	45	50
Standard Deviation	0.0	0.0	0.0	0.0
Departure ROT, s				
Mean	35	35	40	40
Standard Deviation	0.0	0.0	0.0	0.0
IAT Variability, s	0.0	0.0	0.0	0.0
Length of Final Approach, nmi	4	4	3	3

*2.0 for class A behind class A.

TABLE B-6
THEORETICAL UPPER BOUND OF IFR CAPACITY INCREASES

RUNWAY CONFIGURATION	TYPE OF OPERATION: ARRIVALS (ONLY)	DEPARTURES (ONLY)	50% ARRIVALS, 50% DEPARTURES
Single	53.0 (99%)	82.2 (50%)	68.2 (28%)
Dual (700-2499 ft)	53.0 (99%)	82.2 (50%)	106.0 (99%)
Parallel (>2500 ft)	93.2 (153%)	164.6 (50%)	124.8 (69%)

"Realistic" Upper Bound. Parameter values used in the computation of the "realistic" upper bound of capacity increases shown in Figure 4-7 are listed in Table B-7. Mean arrival and departure ROT values are today's; all other parameter reductions represent nominal reductions. A 1-nmi diagonal separation was used for dependent parallel operations. Table B-8 shows the results of the computation using these values.

TABLE B-7
PARAMETERS USED IN COMPUTATION
OF "REALISTIC" UPPER BOUND

PARAMETER	AIRCRAFT CLASS A	B	C	D
Arrival Separations, nmi				
Behind Heavies	5.0	4.0	4.0	3.0
Behind All Others	3.0*	2.5	2.5	2.5
Departure Separations, s				
Behind Heavies (D)	100	100	100	80
Behind All Others (A,B,C)	50	50	50	50
Arrival ROT, s				
Mean	40	40	45	50
Standard Deviation	5	5	5	5
Departure ROT, s				
Mean	35	35	40	40
Standard Deviation	3	3	3	3
IAT Variability, s	9	9	9	9
Length of Final Approach, nmi	4	4	3	3

*2.5 for class A behind class A.

TABLE B-8
ESTIMATE OF "REALISTIC" UPPER BOUND
OF CAPACITY INCREASES IN IFR

RUNWAY CONFIGURATION	TYPE OF OPERATION ARRIVALS (ONLY)	DEPARTURES (ONLY)	50% ARRIVALS, 50% DEPARTURES
Single	36.5 (37%)	63.1 (15%)	58.0 (9%)
Dual (700-2499 ft)	36.5 (37%)	63.1 (15%)	73.0 (37%)
Parallel (>2500 ft)	65.8 (78%)	131.4 (20%)	114.6 (55%)

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GLOSSARY

Acronyms and Abbreviations

ATC	Air Traffic Control
Dep.	Departures
FAA	Federal Aviation Administration
ft	Feet, foot
IAT	Interarrival Time
IFR	Instrument Flight Rules
ILS	Instrument Landing System
kts	Knots
MLS	Microwave Landing System
nmi	Nautical Miles
No.	Number
Ops.	Operations
RNAV	Area Navigation
ROT	Runway Occupancy Time
rwy(s)	Runway(s)
s	seconds
s.d.	standard deviation
VFR	Visual Flight Rules

Terms

Arrival-Priority Operation	The operation of arrivals and departures to an airfield such that the maximum number of arrivals is achieved. (It is not necessary to operate arrivals-only to achieve the maximum number of arrivals.)
Close-Parallel Runway	A runway spaced at least 700 but less than 2500 feet from another parallel runway.

Common Final Approach Path	That part of the final approach path traveled by all classes of aircraft for which the appropriate separations between aircraft are applied.
Departure-Priority Operation	The operation of arrivals and departures to an airfield such that the maximum number of departures is achieved. (Usually a departures-only operation.)
Dependent Operations	Operations in which separation is provided explicitly between aircraft on approach to different runways.
Dual Runways ("Duals") (Also Close-Parallel Runways)	Two parallel runways spaced from 700 to less than 2500 feet apart.
Interarrival Time Variability	The variation in aircraft spacing around the average spacing between specific aircraft pairs. (Does not include variations resulting from differences in required minimum spacings.)
Independent Operations	Operations in which no explicit separation is provided between aircraft on approach to different runways because adequate spacing exists between the runways.
Instrument Procedures	Procedures in which aircraft rely on navigation by the use of ground-based aids to navigation.
Longitudinal Separations	Separations provided between aircraft on approach to the same runway.
Mixed Operations	Operation of both arrivals and departures to an airfield. In this study, only one proportion of arrivals and departures is assumed: 50 percent arrivals.
Multiple Approach Concepts	Concepts that allow simultaneous multiple IFR approaches to different runways on the same airfield.

Operation	Either an arrival to, or a departure from a runway.
Radar Separation	The provision of separation between aircraft by a controller through reference to a radar display of aircraft position.
Runway Occupancy Time	The time an arrival or departure is physically on or above the runway.
"TERPS+3"	A multiple approach concept that allows simultaneous instrument approaches to converging runways under specific circumstances.
Visual Procedures	Procedures in which aircraft are flown by visual references. Separation is usually also maintained by the pilot when flying visual procedures.