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Operational Concepts for Multiple Instrument Approaches

A. L. Haines,* R. M. Harris,† and A. N. Sinha‡
The MITRE Corporation, McLean, Va.

The need to reduce delays caused by airport congestion has gained increased importance with the escalation in fuel prices. Concepts for innovative use of runway geometries, especially in instrument conditions, provide a potential solution. This paper presents several concepts for multiple instrument approaches. These include dependent parallel approaches, converging approaches, and triple approaches. The application to a particular airport is illustrated by the use of all three of these concepts in an evaluation of the Paris airports. It shows the level of detail that is required for applications to individual airports.

Nomenclature

ATC = air traffic control
CDG = Charles-de-Gaulle Airport
FAA = Federal Aviation Administration
IFR = instrument flight rules
ILS = instrument landing system
LBG = Le Bourget Airport
LDA = localizer-type directional aid
MLS = microwave landing system
OM = outer marker
PVD = plan view display
QNH = pressure corrected altitude
STAR = standard terminal arrival
TMA = terminal area
VFR = visual flight rules
VHF = very high frequency
VOR = VHF omnidirectional range

Introduction

MAJOR airports in the United States continue to experience an increase in traffic. Annual airline delay costs now exceed one billion dollars. Increasing fuel costs will raise this number, even without additional traffic demand. Moderate traffic growth may lead to dramatic increases in delay costs because of the nonlinear relationship of delay and demand (particularly as demand begins to meet or exceed available capacity).

Long-term relief may be provided by technology and high capital options included in FAA programs.[1,2] Primary among these are:

1) metering and spacing—automation aids for terminal controllers to increase the precision of delivery of aircraft to the runway;

2) wake vortex systems—devices to detect vortex transport and decay in order to identify conditions where IFR in-trail spacings may be safely reduced;

3) microwave landing systems—advanced approach navigation used to provide noise abatement and operational route separation for high capacity operations.

4) airport surface traffic control—new surveillance techniques and data processing to improve IFR ground control;

5) new airports and air-carrier runways.

Most of these options require considerable investment in the ATC system, airport construction, or avionics equipage. Major additions of new airports or air-carrier runways are considered unlikely before the year 2000.[3] Thus it becomes critical to make the most efficient use of existing resources. Improvements are available at low cost with ATC procedural changes and minor capital investments.

A system-wide plan for relief of airport congestion would address all phases of aircraft flow to the airport. Elements of this plan would include[1,2]: 1) integrated flow management (including central flow control, en route metering, terminal metering and spacing)[4]; 2) configuration management systems (including O'Hare runway configuration management system, terminal area configuration management)[5]; 3) reductions in IFR final approach spacing; 4) short runways for commuters and general aviation; 5) specialized MLS applications; and 6) multiple IFR approach operations.

This paper will concentrate on multiple approaches, with consideration as well of the applications of MLS and short runways, all of which have been extensively researched under FAA sponsorship.

Proposed Concepts

The critical capacity problem at major U.S. airports is typically in the arrival process under IFR conditions. A major feature in improving capacity is to provide for multiple arrival streams. Presently, IFR independent parallel approaches may be conducted in the U.S. to runways spaced by at least 4300 ft.[6] Some reduction in the 4300-ft runway spacing requirement may be possible with the addition of a high resolution, special purpose radar or other improvements.[7]

Dependent IFR parallel approaches are also permitted when successive aircraft on adjacent localizers are separated at least 2 miles on radar.[6] Current usage of dependent parallels with 3000-ft runway spacing is limited. Airport environmental and operational limitations have normally resulted in use of a 3-mile diagonal spacing (rather than 2 miles).

Additional multiple arrival geometries may also be possible. With guidance from the Federal Aviation Administration, The MITRE Corporation has developed initial criteria for the use of these new IFR approach concepts: 1) alternating (dependent) parallel approaches to dual-lane runways (700-2500-ft runway spacing); 2) simultaneous approaches to three parallel runways; and 3) approaches to converging runways.

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*Group Leader, System Analysis. Member AIAA.
†Department Head, Advanced Automation System Engineering. Associate Fellow AIAA.
‡Group Leader, System Requirements and Assessments.

Alternating approaches to dual-lane runways are illustrated in Fig. 1. Aircraft approach two parallel runways and turn on with altitude separation. Once stabilized on the localizer course, a diagonal spacing of 2 nmi. (for example) is maintained. Runway spacings of 700-2500 ft are envisioned. This type of approach extends the current dependent parallel approach concept.

Simultaneous approaches to triple parallel runways are a logical extension to parallel approaches as used today. In this concept, arrival aircraft merge to three parallel approach streams (Fig. 2). These approaches may be all independent along the lines of the 4300-ft rule today. They might also have some elements of the dependent (alternating) parallel approach operation.

Approaches to converging arrival streams are also possible (Fig. 3). This, in general, could not easily apply to intersecting runways, but rather to runways that converge but do not intersect. Initial emphasis is on geometries that permit independent operation. Consideration will also be given to dependent versions. Such dependency might apply where the approaches are relatively close or lateral position-keeping poor.

These concepts are already in daily use under visual or marginal IFR conditions. Chicago O'Hare, Houston Intercontinental, and Washington National, for example, routinely employ approaches to converging runways. Alternating approaches to dual-lane runways are used in San Francisco, Los Angeles, and Denver. Denver uses triple parallel approaches as well. Critical to the success of these VFR procedures is the provision of visual separation by pilot and/or controller. In IFR, all separation must be ensured by nonvisual means.

Application of these basic concepts to individual airports may lead to variation in the concepts. For instance, converging approaches may be used for two of three approach paths, as is done at Chicago O'Hare. Additional airport features may be considered, such as offset runway thresholds and possibilities for addition of separate short (low capital investment) runways for general-aviation and commuter aircraft.[8,9] Traffic segregation may lead to special operational modes and solutions to problems of wake vortex hazards.

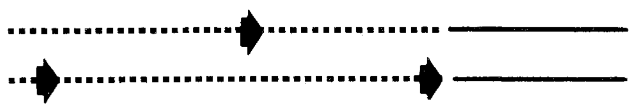

Fig. 1 Alternating parallel approaches.

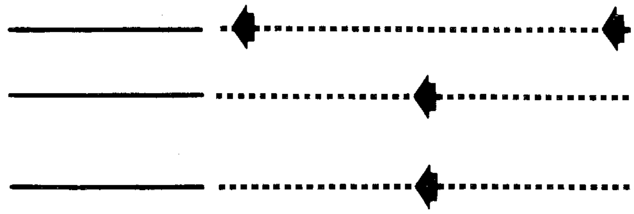

Fig. 2 Triple parallel approaches.

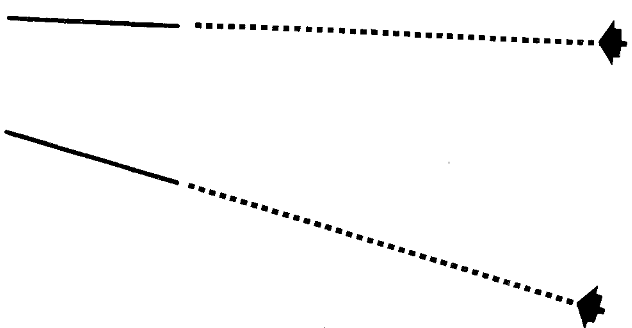

Fig. 3 Converging approaches.

Issues and Requirements

The implementation of new concepts for multiple approaches requires the successful resolution of several issues.

An initial airspace design concept must be established. It must provide for a precise, adequate flow of traffic to each of the approaches. In its initial form, the airspace design must consider the following factors:

1) airport layout (terminal, gates, taxiways, runways, obstacles and other terrain features);

2) airspace structure (glide slope angles, intercept altitudes, common approach paths, noise constraints, obstructions, airspace restrictions, missed approach routes, departure routes, wake vortex constraints, feeder routes, minimum separation requirements);

3) traffic (aircraft mix, demand, usage pattern, aircraft equipage—especially navigation systems).

The capabilities of the controller must be addressed. This starts with an assessment of the adequacy of the surveillance capability. Analysis should consider basic radar accuracy and update rate, computer processing of returns, blind spots, and maximum required range/geometry. Displays to the controller, position definition, workload, and communications capability are also elements of the controller's capability. The issue of the need for a special parallel approach monitor position needs to be addressed.

Finally, the requirements for ATC procedures must be established. These include consideration of such factors as 1) normal navigation error and range of potential blunders (which determine normal operating zone); 2) detection, delay, communication; 3) avoidance maneuvers and net miss distance in event of blunder; 4) pilot/controller workload constraints; and 5) flight characteristics and operational capabilities of aircraft.

These factors together are the ingredients for the determination of safe and effective procedures for multiple approaches. They have been applied previously to the independent parallel arrivals case and have been recently extended to other multiple arrival cases.

Each of the concepts for multiple approaches has a unique emphasis. Alternating (dependent) approaches to dual-lanes have requirements relating to[7,10] 1) vortex transport between approach courses; 2) separation requirements during localizer turn-on; 3) setting, maintaining, and monitoring the diagonal separation (including automation or display aids for the controller); and 4) controller actions in the event of separation violations.

These issues are not new. The controller and pilot cooperate in performing such approaches in visual conditions today. However, visual separation methods always provide for a backup safety capability that is not available under instrument conditions.

Triple parallel approaches have additional requirements on[11] 1) feeding of three approaches (maintaining demand to the runway while providing adequate separation); 2) provision for normal missed approaches (generally with a straight missed approach for the center runway and diverging missed approaches for the other runways); and 3) provision for blunder recovery procedures (where now one blundering aircraft may affect more than one other aircraft).

For approaches to converging runways, the concerns in the arrival area are greatly diminished. With the converging geometry, more airspace is available in the arrival merging area. It is thus easier to feed traffic safely and expeditiously to the two approaches. The major requirements deal with[12] 1) simultaneous missed approaches and 2) blunders during missed approach.

Missed approaches, if continued along the extended runway centerlines, would conflict. Turning missed approaches are required. Boundaries have been developed representing worst case performance during turning missed approaches. These boundaries are not permitted to overlap. Additional safety is achieved by considering that one (but not both) of the aircraft may fail to execute the proper turning missed approach procedure.

With some geometries, the microwave landing system (MLS) may be used to provide for precision missed approaches. For example, MLS could be used to define a smooth, precise straight missed approach for the center approach of triple parallels. It could be used to define precise turning missed approaches, for application to the outer approaches of triples, or to converging approaches. MLS could also be used to define higher angled approaches.[13] For alternating arrivals, placing the lighter aircraft on a higher glide slope could avoid some of the wake vortex hazards.

Operational solutions to some of the requirements can be employed. Use of "upwind" runways can also alleviate wake vortex hazards. Offset thresholds can be used to achieve separation of glide slopes. Separate short runways can be used for smaller aircraft, thus avoiding vortex related (longer) in-trail spacings and inefficient mixing of high and low speed aircraft on the same runway.

Expected Benefits

The benefits of multiple approaches can be significant. Table 1 shows the arrival capacities of single and multiple approaches for two typical mixes of aircraft.

MITRE has taken an initial look at 101 major U.S. airports.[15] This evaluation indicates over 130 potential applications of multiple arrival concepts at 89 different airports.

Application to Paris Airports

The application of the new concepts to a complex airport site can be illustrated by a study performed by The MITRE Corporation for the Aeroport de Paris.[16,17]

Charles-de-Gaulle Airport (CDG) was opened for commercial operations in 1974. The location and the east-west orientation of the runways provided an unavoidable conflict with the ILS approach to Le Bourget (LBG) runway 25. This approach crosses CDG diagonally at low altitudes and conflicts with the westbound approaches to CDG on runways 27 and 28, as shown in Fig. 4. This conflict requires careful coordination of traffic between LBG25 and CDG27, and requires a strict alternation of approaches to the two airports when CDG28 is in use. The maximum capacity of the combined CDG/LBG operation is 62 operations per hour.

At the time of the design of CDG this was not considered to be a problem. It was intended that CDG would grow into full capacity operations with independent parallel approaches, and that LBG would ultimately by phased out of general use, at least in instrument weather conditions. The sustained growth of general aviation and other noncommercial operations, however, coupled with the presence of extensive ground facilities and ease of access of LBG have mandated that efforts be made by Aeroport de Paris to retain a capability for general aviation instrument operations at Le Bourget without imposing restrictions on Charles-de-Gaulle.

This objective is clearly incompatible with the inherent conflicts of the present air traffic control procedure. The forecast peak hourly operations for the two airports run to 75-85 operations by 1995. The present procedures cannot long support the combined peak hour operations. In addition, the growth of operations at CDG will require the routine use of independent parallel approaches, raising the capacity of CDG from 37 to 75 operations per hour, but making impossible the continuation of regular ILS services to LBG25.

The essential ingredient in all proposals for the resolution of the conflicts between the two airports (save that of closing Le Bourget) is to create a system of three parallel or near-parallel approach tracks to the three runways, as illustrated in Fig. 5. The approaches to runways 27 and 28 at Charles-de-Gaulle would be conducted as simultaneous (i.e., independent) parallel ILS approaches with radar monitoring and control provided by the CDG ATC facility. The approach to LBG25 would be conducted on a parallel or near-parallel (5-deg offset) track to the south of the other approach courses. This approach would require a turn to final (17 or 22 deg) conducted under visibility adequate to complete the approach under visual conditions. This approach, too, would be monitored and controlled by the CDG ATC facility until clear of the CDG traffic.

Several options for LBG25 navigation aids were considered. These were (in order of increasing precision of signal):

1) VHF omni-directional range (VOR), operating in the 108.0-117.95-MHz frequency band and providing line-of-sight guidance in all directions from the facility;

2) localizer-type directional aid (LDA), comparable in accuracy and utility to the localizer element of a complete instrument landing system (ILS). It operates on one of 40 channels in the 108.10-111.95-MHz range; course indications are provided in a maximum width of 10 deg from designed

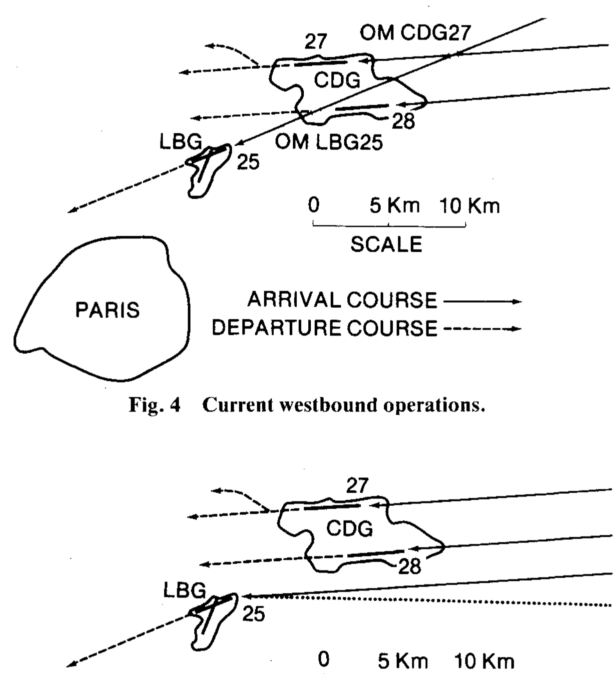

Fig. 4 Current westbound operations.

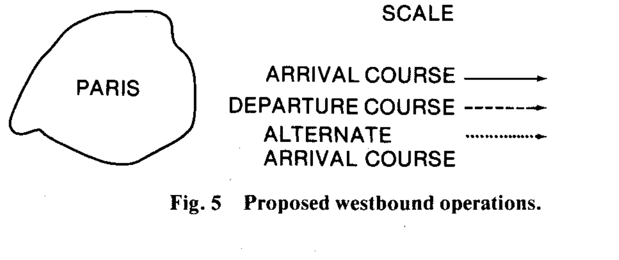

Fig. 5 Proposed westbound operations.

Table 1 IFR arrival runway capacity[14]

	10% heavy aircraft	40% heavy aircraft
Single runway	28	25
Dependent parallels[a]	39	38
Independent parallels	55	51
Independent converging approaches	55	51
Triple parallels[b]	67	64

[a]2-nmi. diagonal, 3000-ft centerline separation. [b]One dependent parallel pair.

heading, with a design range of 18 nmi. (although greater ranges are routinely achieved);

3) microwave landing system (MLS), operating in higher frequency ranges, and providing proportional guidance to a wide range of lateral azimuthal angles; features such as curved approach paths, flare guidance, and missed approach guidance can be provided.

The proposed operations for the Paris LBG/CDG complex elaborate on current U.S. instrument parallel procedures in several aspects:

1) Triple parallel approaches are envisioned for the westbound configurations. (All current approaches involve only two parallels.)

2) Parallel approaches are made to two separate airports. (All current parallel approaches are to a single airport.)

3) The LBG25 approach requires a turn from the approach course to the runway. (All current IFR approaches are straight in.)

4) Course guidance for the LBG25 approach is expected to be provided in the near term by a VOR, or perhaps later by another nonprecision aid. (All current parallel approaches are performed with conventional ILS equipment and installations.)

5) A version of a LBG25 approach to be considered is 5 deg from parallel with the CDG approaches. (All current experience is with strictly parallel approaches.)

The solution elements address the areas of airspace layout, approach procedures, manpower needs, and equipment requirements.

Airspace Considerations

The Paris TMA is divided into discrete areas dedicated for CDG/LBG to the northeast and for Orly to the south and east of Paris. Three arrival fixes serve CDG and LBG. These fixes must be linked to a final approach for each airport. Figure 6 shows the proposed tracks for high traffic periods in westbound operations. These tracks take into account the relative traffic loadings of each of the three fixes to provide roughly equal traffic assignments to CDG runways 27 and 28. The altitudes of glide path intercept are governed by the need to provide 1000 ft of altitude separation while the aircraft turn to and stabilize on the final approach guidance. The 3000 ft (QNH) altitude is the lowest compatible with noise alleviation requirements. The top altitude of 5000 ft (QNH) is assigned to the LBG approach to allow aircraft for this approach to be merged without interference to the CDG traffic at the lower altitudes. The length of the final segments is governed by the need to provide 3 nmi. of level flight prior to glide path intercept. To minimize the length of the final segments, the 4000-ft intercept is assigned to CDG27. This establishes the turn on points at about 14 nmi. from the threshold of CDG27 as shown.

Missed Approach

Specific, coordinated missed approach procedures are essential to parallel operations, especially when triple parallels are contemplated. Missed approach courses diverge by 45 deg (once a minimum maneuver altitude of 400 ft is reached). Thus the missed approach for CDG28 holds runway heading, while that for CDG27 turns northwest and for LBG25 southwest. Each has an assigned VOR radial and holding fix to which the aircraft can proceed without controller intervention. Multiple missed approaches, especially those initiated by an aircraft blunder, will be rare. However, it is prudent to provide reserved missed approach airspace (as shown by the shaded areas of Fig. 6). In the event of a blunder (deviation from centerline) this allows the controllers to direct one or more aircraft on the outboard tracks to execute the missed approach procedure, and then direct their attention to the maneuvering of any other aircraft involved.

Departures

Departures remain much as at present. Two changes are introduced, however, for traffic departing to the east and south to protect the reserved missed approach airspace. In addition, required separation between CDG28 departures and LBG25 arrivals is provided on a procedural (nonradar) basis. This is done by prohibiting CDG28 departures when an LBG25 arrival would come within 2 nmi. of a departure.

Equipment and Manning

The operation of independent parallel ILS approaches requires that a special parallel monitoring controller be assigned to each independent element of the operation. In the case of the operation described above, one monitor observes CDG27 and the other CDG28/LBG25. The two controllers are stationed at a separate PVD with calibrated map information showing the runway course centerlines, and normal operating zones. Clear channel air/ground and internal communications are provided to each controller. The

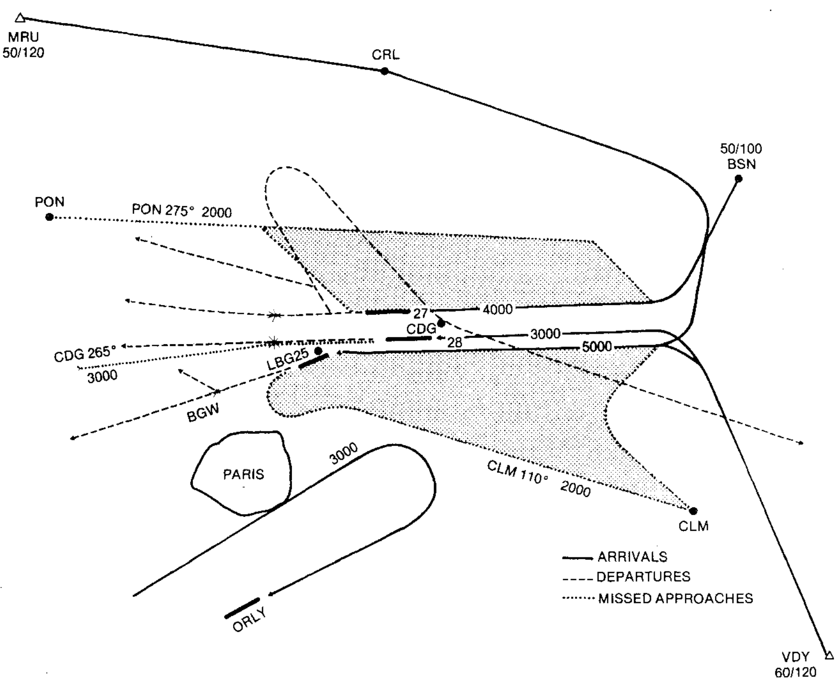

Fig. 6 Proposed westbound airspace organization.

Table 2 ATC implications of options

ATC scenario	Means of achieving
Two dependent LBG/ CDG arrival streams	Current
Two independent CDG arrival streams	Close LBG, or make dependent on CDG operations
CDG27 independent, CDG28/LBG25 dependent	
3-nmi. stagger	LBG25 VOR[a]
	LBG25 VOR (nonparallel)
2-nmi. stagger	LBG25 LDA
CDG27/CDG28/LBG25 arrival independent (CDG28 departures dependent on LBG25 arrivals)	LBG25 LDA (nonparallel)
	LBG25 MLS

[a] If VOR error can be established below nominal specification value.

monitoring task consists of observing the positions of all assigned aircraft at each radar update (4 s). Aircraft are monitored from the point at which the 1000-ft altitude separation is lost (at glide path intercept). Should an aircraft be observed to leave the centerline of the approach course, it is given an advisory to return. If it exits the normal operating zone, it is declared a deviator. No further action is taken to return the deviator to course, since it must be assumed to be out of control. The two controllers coordinate to issue missed approach instructions to any other aircraft on final that may be threatened by the deviator.

Navigation Alternatives

The analysis of the navigation options assumed that adequate radar coverage was available. Under this assumption, the governing factor in the spacing of the LBG25 approach course is the signal-in-space accuracy of the navigation aid and the pilotage achieved on the approach. The analysis of navigation alternatives results in the ATC implications of each navigation option. These are summarized in Table 2.

The capacity of the combined independent/dependent alternative (supported by a VOR or LDA) is sufficient to meet the demand into the 1990s. At that time, a fully independent triple arrival operation may be required (supported by an LDA or MLS). Currently, the Aeroport de Paris is proceeding with the VOR option.

Conclusions

Several new concepts for multiple IFR arrival approaches and their initial implementation requirements have been defined. There is indication of applications at significant numbers of airports within the United States. The application of these concepts to the Paris airports illustrates the site specific nature of any application, as well as the significant improvements in arrival capacity during instrument conditions.

Acknowledgments

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