1.231J/16.781J/ESD.224J **Fall 2007**

ASSIGNMENT # 1

(Out: September 13; due: September 27)

<u>Problem 1: A Capacity Envelope</u> (32 points)

In this problem you will compute the capacity envelope (Section 10.6 of the textbook) of a single runway under a specified set of somewhat simplified conditions.

The following information is given about air traffic at that runway:

(a) Aircraft can be classified into 3 types: heavy (H), large/medium (L), and small (S).

(b) Some relevant aircraft characteristics are as shown in Table 1 below:

Aircraft type	Approach speed (knots)	Mix (%)	Runway occupancy time on landing (seconds)
H	150	30	70
L	135	40	60
S	105	30	50

Table 1

(c) The length of the final approach to the runway is 6 n. miles.

(d) The minimum separation requirements (in nautical miles) between successive landing aircraft on final approach are given by Table 2 below (rows indicate the leading aircraft and columns the following aircraft):

	H	L	S
H	4	5	6*
L	2.5	2.5	4*
S	2.5	2.5	2.5

[*= These separations apply only when the leading aircraft is at the runway threshold; all the other separations apply throughout the final approach]

Table 2

(e) A "buffer time" of 15 seconds (see Section 10.5 of de Neufville and Odoni textbook) is added to all the minimum acceptable separation times between successive landings to account for uncertainty in spacing aircraft.

(f) The minimum separation requirements (in seconds) between successive departing aircraft are given by Table 3 below (rows indicate the leading aircraft and columns the trailing aircraft):

	H	L	S
H	90	120	120
L	90	90	90
S	60	60	60

Table 3

As in Section 10.6, we shall approximate the capacity envelope as a polygon defined by four points 1 – 4.

Part 1: Find Point 1 ("all arrivals" point): assuming this runway is used for arrivals only, what is its (maximum throughput) capacity.

Part 2: Find Point 4 ("all departures" point): assuming this runway is used for departures only, what is its (maximum throughput) capacity. [No buffer times are added for departures.]

Part 3: Find Point 2 ("free departures" point) under a set of assumptions described below. [Note that, under the simplification introduced in (g) below, the "free departures" consist of S aircraft only.] *Please also note that the number of S aircraft given a "free departure" cannot exceed 30% of the "all arrivals" capacity* (why?).

(g) During peak departure periods, ATC sends some Type S aircraft (only) to this runway for take-off. Specifically, they try to insert as many type S departures as possible, between consecutive arrivals while observing the following rules (h) – (k).

(h) The departures will not in any way affect the arrival rate; in other words, separations between successive arrivals, as shown in Table 2, will not be increased in any way in order to accommodate departures. (Assume also that the 15-second buffer time – see (e) above – continues to be added to the separation between each pair of consecutive landing aircraft.

(i) A departure inserted between two arrivals can begin its takeoff roll only after the leading arrival has exited the runway and must lift off the runway before the trailing arrival touches down on the runway. Note that the time needed for an arriving aircraft to exit the runway is given by the runway occupancy time on arrival shown under (b). Assume also that the time during which an arriving aircraft occupies the runway, provides sufficient time for a departing aircraft of Type S to enter the runway and get ready to begin its take-off roll. (In other words, the takeoff roll can begin immediately after the preceding arriving aircraft exits the runway.)

(j) The runway occupancy time on takeoff of type S aircraft is 50 seconds. This is the time from beginning of takeoff roll to lifting off the runway.

(k) If two or more departures are to be inserted between a pair of arriving aircraft, the minimum separation time between consecutive departures of type S aircraft is 60 seconds, as shown in Table 3.

Part 4: Find Point 3 (“alternating arrivals and departures” point) under a set of assumptions described below. Note that, in this case, the runway, by design, handles an equal number of landings and of takeoffs in each hour.

(l) The local air traffic controllers use an operations-sequencing strategy of alternating landings and takeoffs on the runway, i.e., during periods of continuous demand, a landing is always followed by a takeoff, which is then followed by a landing, etc. Thus, when the minimum required time gap between two landing aircraft, *i* and *j*, is not sufficient to insert a takeoff, the time gap will be increased by ATC appropriately. (By ‘time gap’ we mean here the minimum separation time *plus* the 15-second buffer.)

(m) Takeoffs wait next to the threshold of the runway. As soon as a landing aircraft crosses the runway threshold, the next departing aircraft enters the runway and prepares for the takeoff run. It takes 45 seconds for a departing aircraft of any type to enter the runway and set up for take-off. (Note that, in the meanwhile, the arriving aircraft that just landed is moving down the runway toward a runway exit.)

(n) A takeoff run cannot begin until the preceding landing aircraft has cleared the runway.

(o) Once a takeoff run begins, the runway occupancy time for *all* departing aircraft (time from the beginning of the takeoff run to clearing the runway) is equal to 60 seconds. [Making runway occupancy times on takeoff equal for all departing aircraft is a reasonable approximation that simplifies calculations.]

(p) The separation between two consecutive takeoffs must be at least 90 seconds in all cases (i.e., disregard for now the separation matrix shown in Table 3).

(q) A landing aircraft is not allowed to cross the runway threshold unless the runway is clear of departing aircraft, i.e., the preceding departure has lifted off. (Note that this is the *only* "departure-followed-by-arrival" separation requirement.)

[*A helpful example regarding Part 4:* Consider a pair S-H of consecutive arrivals (“arrival of S followed by arrival of H”): The separation between the arrivals in this case will be 75 seconds [=(2.5/150)x3600 +15]. But to insert a departure, we need 110 seconds (50 for the arriving S aircraft to leave the runway plus 60 for the takeoff run of the departing aircraft. Thus, the required separation between the S and H arriving aircraft is equal to max (75, 110) = 110 seconds. This requires increasing the separation between the two arriving aircraft by 35 seconds (compared to the arrivals-only case) so that we can insert a departure between the two arrivals.]

Part 5: Please sketch the runway capacity envelope for this case, as determined after the set of simplifying assumptions we have made. Is it feasible to handle 22 arrivals and 15 departures at this runway in one hour?

Part 6: Please return to Part 4 above and re-consider Assumption (p). Specifically, assume that, instead of Assumption (p), it was stated that the separation between two consecutively departing aircraft (with one intervening arrival between the two departures) must satisfy Table 3. Would your answer to Part 4 change? If your answer is "no", please explain clearly why not. If it is "yes", please indicate why and describe briefly how you would find the correct answer (you do not have to give a specific new answer).

<u>Problem 2: The Impact of the A380 on Airport Capacity</u> (16 points)

One of the principal questions associated with the introduction of the A380 into service is its impact on runway capacity. Because of its size and potential wake effects an ICAO committee recommended last year that, at least initially, (a) the A380 be treated as a separate class of aircraft for ATC separation purposes and (b) the required separations for aircraft trailing the A380 be set at very conservative levels. It has been suggested that, if these recommendations are implemented, the A380 will have a significant negative effect on runway capacity. In this problem you are asked to explore this issue through a simple numerical exercise.

One potential set of separations on final approach, following the introduction of the A380, might be the one given in Table 4 below (for convenience, we have omitted the B757, as a separate class):

		Trailing Aircraft			
		A380	H	L	S
Leading Aircraft	A380	6	6	8	10*
	H	4	4	5	6*
	L	2.5	2.5	2.5	4*
	S	2.5	2.5	2.5	2.5

* Separation applies only when the leading aircraft is at the threshold of the runway.

Table 4

Consider now a runway used only for arrivals at a major airport, such as London Heathrow. Assume that the current traffic mix at the airport is the following: with a current traffic mix as given in Table 1 (Problem 1).

It is logical to assume that any future A380 flights at this airport will replace, at least early on, flights currently performed by "Heavy" aircraft. Given the small number of A380 orders to date (about 130 firm) it is also reasonable to assume that the maximum presence of the A380 in the traffic mix during *any* hour of the day will be 20% of all landing aircraft.

(a) For the separation matrix in Table 4 compute the arrivals capacity of this runway when the presence of A380s in the mix is 0%, 5%, 10%, 15% and 20%.

(b) Write two or three paragraphs assessing the overall initial impact of the A380 on capacity as measured by the number of aircraft movements and by the number of aircraft seats that can be served per hour on a runway. What if the A380 is eventually classified as just another "H" aircraft for ATC purposes? As background, note that the BAA announced recently that it is spending almost $900 million to upgrade Heathrow Airport so it can handle the A380.

Problem 3: Third Runway at Munich Airport (16 points)

The following announcement was made in August 2006 by FMG, the operator of Munich International Airport in Germany:

> **FMG requests start of regional planning process**
>
> The Munich Airport operating company, FMG, has applied this week to the Regional Government of Upper Bavaria for the initiation of a regional planning process for the construction of a third runway. In addition to detailed reasons for the planned expansion measure, the application contains 18 expert reports and planning documents, including air traffic forecasts, two capacity reports and an environmental impact study. The application documents fill eight ring binders, and include several thousand pages and about 100 plans.
> In this process, FMG is applying for the so-called 5b runway option. In relation to the existing northern runway, it has an axial displacement of 1180 meters and a so-called threshold offset of 2100 meters. The preferred option is the outcome of the analysis of the more than two dozen sites originally considered. Of the six runway locations with which the airport could achieve the goal of 120 schedulable take-offs and landings per hour, FMG believes that the 5b option requested in the application best meets the needs of all concerned parties.

Please write two or three paragraphs and do a simple supporting analysis to explain the above announcement. Munich Airport (see slide shown in Lecture 2 on Airport Characteristics) currently operates with two (long) independent parallel runways, with a separation between their centerlines equal to 2,300 m. You can go to to obtain some (but not much) additional information about the airport, as it stands today.

Your answer should address the following two points:

(a) Explain why "an axial displacement of 1180 meters and a so-called threshold offset of 2100 meters".

(b) Is it reasonable to expect that the goal of "120 schedulable take-offs and landings per hour" will be met with the addition of the third runway, as described above? All you need to do is argue briefly whether “120 movements per hour” is in the “right ballpark” or not. [Your answer to this should be based only on some “back-of-the-envelope” calculations after: (i) making a reasonable assumption regarding future traffic mix – for instance, is “70% Heavy, 20% Large, 10% Small” reasonable for Munich?; (ii) assuming FAA IFR separation requirements (certainly reasonable); and (iii) making a reasonable assumption regarding how each runway will be used in heavy traffic – arrivals only, departures only, mixed operations.]

<u>Problem 4: Intersecting Runways – A Simplified Example</u> (16 points)

An airport consists of two intersecting runways whose approximate geometric layout is shown on Figure 2. Runway 01 is used only for arrivals and runway 10 only for departures. We want to compute the runway capacity of the airport under the conditions described below. (Some of the information provided may not be particularly useful in doing the problem.)

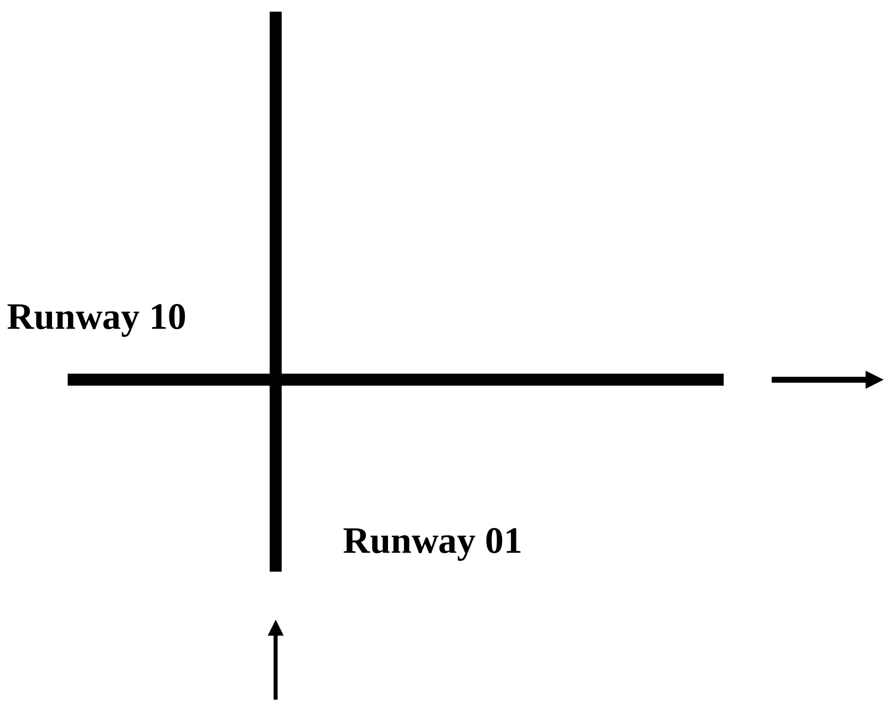

Figure 2

Just one (!) type of aircraft uses the airport. Aircraft of this type are characterized by: a final approach speed of 150 knots; runway occupancy times of 50 seconds on arrival (time between the touchdown of the arriving aircraft and the instant when it exits the runway); and runway occupancy times of 60 seconds on departure (time between the beginning of the takeoff roll of the aircraft and its lift-off from the runway).

The separation required between successive landing aircraft of the type in question while flying on final approach is 4 nautical miles (nmi). This indicates the minimum acceptable distance between successive landing aircraft at any point during their final approach. The length, n, of the final approach is 5 nmi.

Successive departing aircraft of the type in question must be separated by 90 seconds between the beginning of take-off rolls.

During peak periods this runway system is operated by alternating arrivals and departures: an arrival on runway 01 is always followed by a departure on runway 10, which is always followed by an arrival on runway 01 and so on. An arrival on runway 01 must be at least 1 nmi away from the beginning of runway 01 at the instant when the preceding departure *crosses the intersection* of the two runways. Similarly, a departure roll on Runway 10 cannot begin before the preceding arrival crosses the intersection of the two runways.

Assume that all arriving aircraft need 20 seconds from the instant they cross the beginning of Runway 01 to the instant when they cross the intersection of the two runways. Similarly assume that all departing aircraft require 30 seconds from the instant they begin their takeoff roll on Runway 10 to the instant when they cross the intersection of the two runways.

(a) What is the capacity of this system in terms of total number of movements (landings and takeoffs) per hour? Note that air traffic controllers will adjust the separations between successive operations to make sure that no separation requirement mentioned above will be violated. For example, an arriving aircraft must (a) be separated by at least 4 nmi from the preceding arrival during final approach, (b) cannot touch down on the arrival runway before the preceding arrival has exited the runway and (c) must be at least 1 nmi from the beginning of Runway 01 at the instant when the preceding departure crosses the intersection of the runways.

(b) Repeat part (a) with the following data for the characteristics of the aircraft:

Approach speed = 120 knots
Runway occupancy time on arrival = 45 seconds
Runway occupancy time on departure = 50 seconds
Minimum separation between successive arriving aircraft on final approach = 2.5 nmi
Minimum separation between beginning of take-off roll of successive departing aircraft =
= 60 seconds

All other information (mode of operation, times to cross intersections, etc.) is the same as in part (a).

<u>Problem 5: Airport Design Standards</u> (20 points)

This is not a "problem" in the traditional sense, but a multiple-choice test developed by the FAA for checking your understanding of the FAA's Airport Design Standards. Please answer all the questions on the attached FAA test **with the exception of questions 10, 24, 27, 28 and 29**. The intent here is to give you an incentive to at least familiarize yourself with the Airport Design Standards as described in Chapter 9 of the FAA's training manual on *Airport Planning Criteria* -- a large portion of which will be distributed as a class handout. While reviewing that handout, you may also wish to use Sections 9-2, 9-3, 9-5, 9-6, 9-7, 9-8 and 9-9 of the de Neufville and Odoni textbook for background information. The original and most appropriate reference for all this is the FAA document *Airport Design Advisory Circular 150/5300-12*, originally published in 1983 and updated several times since then. The Aero/Astro Library (1st floor, Building 33) has copies.