Optimal Design of Departure and Arrival Routes in Terminal Maneuvering Area

I. Input data and numerical results of the simulation tests

A. Test 1, generation of 2 SIDs and 3 STARs ($N = 5$)

The input data related to the traffic load (in percentage), the starting and ending points, and the characteristics of the buffer obstacles of each route to design are presented in Table 1.

The numerical results of case 1 ($N = 5$, $M = 0$) and case 2 ($N = 5$, $M = 9$) are presented in Table 2, the unit is in Nm. Note that $L_{\gamma_i^0}$ and $L_{\gamma_i^{cur}}$ are computed using the weight coefficient $c_1 = 1$, $c_2 = 0$, thus the length of level flights is not penalized. Let $\ell^0_{i_{LF}}$ (respectively, $\ell^{cur}_{i_{LF}}$) be the length of level flight on route γ_i^0 respectively, γ_i^{cur}, and let $\ell^0_{i_{cflt}}$ (respectively, $\ell^{cur}_{i_{cflt}}$) denote the total length of conflicting route sections on γ_i^0 (respectively, γ_i^{cur}), their values are presented in Table 2. The proposed B&B-based approach solves all conflict in both cases.

Table 1 Test 1: input data related to routes to design

γ_i–SID/STAR–traffic load	starting point		ending point	buffer obstacle		
	(x_{A_i}, y_{A_i}) (Nm)	H_{A_i} (ft)	(x_{B_i}, y_{B_i}) (Nm)	$(x_{b_i}, y_{b_i}, r_{b_i})$ (Nm)	$(z_{b_{i_{inf}}}, z_{b_{i_{sup}}})$ (ft)	$t_{\Omega_{b_i}}$
γ_1 – SID – 30%	(21, 89)	0	(75, -18)	(20, 84, 2.5)	(0, 50000)	0
γ_2 – SID – 25%	(4, -8)	0	(55, 93)	(3, -3, 2.5)	(0, 50000)	1
γ_3 – STAR – 20%	(30, -20)	0	(42, 99)	(35, -18, 2.5)	(0, 50000)	0
γ_4 – STAR – 15%	(65, 66)	0	(-12, 66)	(62, 72, 2.5)	(0, 50000)	0
γ_5 – STAR – 10%	(-15, 50)	0	(51, -11)	(-12, 43, 2.5)	(0, 50000)	0

Table 2 Test 1: numerical results

Test 2	Case 1, $N = 5$, $M = 0$ (unit in Nm)						Case 2, $N = 5$, $M = 9$ (unit in Nm)					
	initial routes			optimal routes			initial routes			optimal routes		
	$L_{\gamma_i^0}$	$\ell^0_{i_{LF}}$	$\ell^0_{i_{cflt}}$	$L_{\gamma_i^{cur}}$	$\ell^{cur}_{i_{LF}}$	$\ell^{cur}_{i_{cflt}}$	$L_{\gamma_i^0}$	$\ell^0_{i_{LF}}$	$\ell^0_{i_{cflt}}$	$L_{\gamma_i^{cur}}$	$\ell^{cur}_{i_{LF}}$	$\ell^{cur}_{i_{cflt}}$
γ_1 – SID	123.36	0	0	123.36	0	0	124.59	0	0	124.59	0	0
γ_2 – SID	116.66	0	2.56	119.08	0	0	117.32	0	9.06	121.02	0	0
γ_3 – STAR	126.03	0	4.12	128.01	0	0	126.45	0	0	126.45	0	0
γ_4 – STAR	84.43	0	9.16	91.56	11.23	0	84.56	0	6.72	84.56	32.77	0
γ_5 – STAR	92.18	0	9.51	95.95	0	0	92.99	0	9.4	101.48	0	0
Total	542.66	0	25.35	557.75	11.23	0	545.91	0	25.18	558.1	32.77	0

B. Test 2, generation of multiple routes in the TMA of Paris CDG airport

The starting and ending points, and characteristics of the corresponding buffer obstacles of each route to design are presented in Table 3.

A comparison in terms of route lengths is presented in Table 4 (unit in Nm). In order to compute the total length of the standard routes, we complete manually the approach phase of the standard STARs, by connecting them to the FAF that we use in the simulation.

Table 3 Test 2: coordinates of the starting and ending points, and corresponding buffer obstacles of the selected routes

γ_i	threshold	starting point		ending point	buffer obstacle		
		(x_{A_i}, y_{A_i}) (Nm)	H_{A_i} (ft)	(x_{B_i}, y_{B_i}) (Nm)	$(x_{b_i}, y_{b_i}, r_{b_i})$ (Nm)	$(z_{b_{i_{inf}}}, z_{b_{i_{sup}}})$ (ft)	$t_{\Omega_{b_i}}$
γ_2	09R	(99.28, 122.95)	370	(159.87, 132.61)	(96.07, 124.59, 2)	(0, 50000)	1
γ_9				(73.18, 175.07)			
γ_{11}				(167.34, 118.76)			
γ_{12}				(107.11, 171.69)			
γ_{13}				(48.26, 122.38)			
γ_3	08L	(100.9, 121.5)	338	(111.77, 67.03)	(93.29, 117.61, 3)	(0, 50000)	0
γ_5				(80.87, 66.08)			
γ_{14}				(31.89, 113.55)			
γ_1	27R	(111.12, 124.51)	3392	(207.18, 177.27)	(112.55, 129.61, 4.9)	(0, 50000)	0
γ_4				(45.4, 176.02)			
γ_8				(158.66, 193.36)			
γ_{15}				(12.31, 138.75)			
γ_6	26L	(112.8, 122.66)	3316	(29.88, 75.39)	(115.07, 120.4, 2.5)	(0, 50000)	1
γ_7				(211.86, 61.57)			
γ_{10}				(208.23, 23.08)			

Table 4 Test 2: numerical results

i	routes obtained by B&B-based approach						standard routes	$length - L_{\gamma_i^{cur}}$
	initial routes			optimal routes				
	$L_{\gamma_i^0}$	$\ell^0_{i_{LF}}$	$\ell^0_{i_{cflt}}$	$L_{\gamma_i^{cur}}$	$\ell^{cur}_{i_{LF}}$	$\ell^{cur}_{i_{cflt}}$	$length$	
1	109.79	0	0	109.79	0	0	115.19	5.4
2	73.58	0	0	73.58	0	0	75.85	2.27
3	69.98	0	0	69.98	0	0	77	7.02
4	95.65	0	0	95.65	0	0	110.38	14.73
5	65.26	0	0	65.26	0	0	75	9.74
6	105.3	0	12.44	105.3	25.71	0	110.4	5.1
7	116.94	0	0	116.94	0	0	120.38	3.44
8	84.89	0	0	84.89	0	0	97.09	12.2
9	60.98	0	10.73	67.69	0	0	59.62	-8.07
10	139.04	0	0	139.04	0	0	139.28	0.24
11	81.2	0	0	81.2	0	0	84.16	2.96
12	55.24	0	6.7	61.36	0	0	55.51	-5.85
13	51.04	0	0	51.04	0	0	51.25	0.21
14	69.46	0	0	69.46	0	0	69.57	0.11
15	117.16	0	18.23	122.31	29.91	0	117.58	-4.73
Total	**1295.51**	**0**	**48.1**	**1313.49**	**55.62**	**0**	**1358.26**	**44.77**