A PROPOSAL FOR REVISED APPROACHES AND PROCEDURES TO MALTA INTERNATIONAL AIRPORT

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Abstract

Malta International Airport (ICAO code LMML) has four runways organized in T-format. The longer two are usually used by commercial aircraft since they are equipped with an Intrument Landing System and are facing local prevailing winds. The shorter two are mainly used for general aviation and for commercial airport adopting visual flight rules. Conventional procedures to and from the airfield are published in the Aeronautical Information Package, and include Standard Instrument Departures, instrument T-bar approach charts and other visual charts. However, no Standard Terminal Arrival Routes to connect inbound fixes to initial approach fixes or equivalent waypoints are available.

This paper describes in detail the methodologies adopted in designing revised SIDs, STARs and associated procedures aimed at introducing optimal approaches and departures from LMML for the reduction of greenhouse gases in Maltese airspace. The resulting procedures for runway 13, which is the most heavily used runway by commercial aircraft, are presented, analyzed and discussed.

1 Introduction

The profile flown by aircraft can be described both vertically and laterally. In and around the terminal areas, routes tend to be tightly regulated, with formal routes that aircraft are required to fly being published and known as Standard Instrument Departures (SIDs) and Standard Terminal Arrival Routes (STARs). The design of SIDs and STARs is specified by ICAO DOC 8168 [1]. The STAR is a designated instrument flight rule (IFR) arrival route linking a particular waypoint, normally on an Air Traffic Service (ATS) route, with a second waypoint from which a published instrument approach procedure can then be commenced. Likewise, a SID is a designated IFR departure route linking the aerodrome or a specified runway of the aerodrome with a specified specific waypoint, normally also on a designated ATS route but at which the en-route phase of a flight then commences [1].

Malta International Airport, the country’s only operational airport is located at Luqa airfield. It has four runways organized in T format, namely runway 13, 31, 05, 23. Usually, runways 13 and 31 are used by commercial aircraft since they are equipped with Instrument Landing System certified to CAT I but are flight checked to CAT II standards [2]. Runways 31-13 are also much longer than 23-05, the former’s published length being 3355 m and the latter 2377 m. Furthermore, and not surprisingly, the longer and better equipped runways face local prevailing winds (north-westerlies and south-easterlies).

The Aeronautical Information Package (AIP) publishes conventional SIDs, instrument T-bar approach charts and other visual arrival and departure charts for all runways [2]. The former two are used for IFR procedures, whilst the third is utilized by flights under visual flying rules (VFR). Until now, there are no published standard arrival routes to connect inbound fixes to initial approach fixes or equivalent/alternative waypoints. The scope of the work associated with this paper is to develop, as part of a nationally funded Research and Technological Development Infrastructure (RTDI) programme

CLEAN FLIGHT[1], revised SIDs, STARs and associated procedures that are sensitive to the environmental impact aviation has on the environment. This will, of course incorporate the proposal of new Required Navigation Performance (RNP) procedures into and out of LMML, taking into account the geographic and demographic characteristics of the Maltese islands, operational constraints (such as general aviation activity mixed with commercial operations and the presence of restricted areas) as well as environmental considerations such as perceived noise, carbon emissions, operational costs and safety.

The departure and arrival routes for LMML proposed in this work have been designed for aircraft equipped with Area Navigation (RNAV), with a capability of flying within RNP 1 (required navigational performance of 1 nautical mile). From an academic perspective, this level of accuracy is adequate since no appreciable high ground is present in the vicinity of the airfield. Nevertheless, for arrivals a higher level of navigational accuracy is required as the aircraft approaches the final approach fix or the capture cone of the ILS. Departure routes were designed to incorporate fixed radius turns given the precision and accuracy that RNP 1 equipped aircraft can maintain while following such turns. To respect the design criteria established by ICAO, the RNAV routes were designed to be compatible with aviation industry guidelines, in particular ARINC 424-17 'Navigational System Database', which is a standard used to code terminal procedures into the Flight Management Computers (FMC) of aircraft [3], [4].

When designing these lateral routes, waypoints and track distances have to be defined according to WGS-84 standards. However, the Spherical Earth Transverse Mercator (UTM) coordinate system was used to find the location of these waypoints and appropriate transformations were utilized to convert all relevant navigational data to WGS-84 standard.

In this paper, the methodology used to design the new lateral paths is explained and the resulting SIDs and STARs for runway 13 only are included, analyzed and discussed.

2 Methodology

The Aircraft Operation Manual for the construction of Visual and Instrument Flight Procedures, Doc 8168 Vol II, was used as the main reference procedure handbook to design the RNAV and RNP routes, given that it is the international standard used for the design of departures and arrivals within Europe [5].

2.1 The current air traffic management structure at LMML

Malta's Airspace covers a large rectangular shaped area over the central Mediterranean basin, with the Maltese Terminal Area lying within the West Flight Information Region (FIR). The latter region is enclosed by a number of feed waypoints as seen in Fig. 1. All these waypoints feed in and out of GZO VOR/DME, except for DIBAK and GODAK, which feed in and out from MLT NDB. There are a number of noise abatement procedures included in Malta's AIP. In general, in calm wind and good weather conditions, noise abatement and noise distribution will determine the runway usage. Local ATC tend to select runway 13 as the main runway for landings and take-offs between 1800-0600 hrs (local time) and runway 31 between 0600-1800 hrs, unless the tailwind component exceeds 5 knots and/or the runway surface is wet. This is not applicable when wind shear has been reported or forecast, or when thunder storms are expected to affect the approach or departure.

The noise abatement procedures for arriving aircraft are as follows:

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[1] CLEAN FLIGHT is a programme funded by the Maltese Government and focuses on reducing the impact commercial aircraft flying on the approaches to Malta have on the environment.

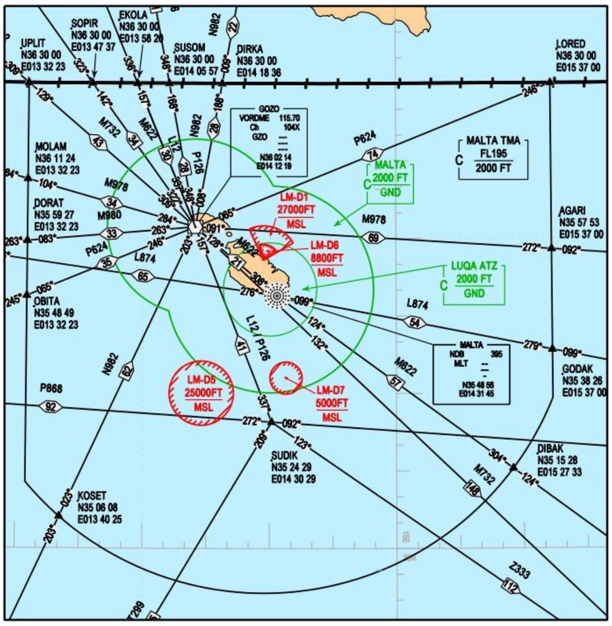

Fig. 1. Malta's Terminal Area [2].

- Aircraft using an ILS have to abide with the following altitude and speed restrictions: Leave the IAF at 210 KT ± 10 KT and maintain this speed until 9 NM from touchdown (unless higher IAS is required for control purposes);
- Reduce to 160 KT ± 10 KT using an intermediate flap setting with landing gear retracted;
- Intercept the glide path at not lower than the prescribed glide path interception altitude, i.e. not lower than 3000 ft;
- Lower the landing gear, set flaps for landing and establish final approach speed between 4 NM and 5 NM from touchdown.

It is also required that all departing aircraft follow speed and altitude recommendations for noise abatement, listed in Table 1.

Within Malta's terminal area there are four danger zones, LM-D1, LM-D5 AND LM-D6 which are advertised by way of a NOTAM, and LM-D7 which is advertised via voice radio by ATC [2]. LM-D7 does not affect commercial aircraft since it is active only from sea level up to 5000ft, and therefore does not intersect with the vertical profile of departing and arriving traffic at LMML, when flying through this region.

A review of the local traffic trends was carried out analyzing all the inbound and outbound traffic from January 2010 until October 2011. From this analysis it was verified that the most popular traffic trends, both inbound and outbound, are from the North West of Malta. The popular exit and entry points were then identified, these being ADEXI, DILIN and NELDA for outbound flights (exit points), and MARON being the most common entry point.

Take-off to 1800 ft	Take-off power Take-off flaps Climb at V_2 + 10 KT to 20 KT (or as limited by body angle).
At 1800 ft	Reduce thrust to not less than climb power/thrust.
1800 ft – 3300 ft	Climb at V_2 + 10 KT to 20 KT.
At 3300 ft	Accelerate smoothly to en-route climb speed with flap retraction on schedule.

Table 1: Noise abatement procedures for departing aircraft.

2.2 Design parameters and earth models

Given that the Boeing 737NG and the Airbus A320 series of aircraft constitute nearly all the commercial traffic flying in and out of LMML, the SIDs and STARs that are proposed in this paper were designed for category C aircraft[2].

To find the turn radius for departures and approaches at a defined typical bank angle, a typical design speed is specified in DOC 8168 VOL II for each aircraft category. For departures, an omni-directional wind of 30 knots was taken into consideration, while for approaches the ICAO standard wind was calculated as shown in equation (1), where 'h' is the altitude in thousands of feet and V_W is the resulting wind speed in knots [6].

$$V_w = 2h + 47 \qquad (1)$$

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[2] Category C aircraft have a runway threshold speed (V_{at}) in the region of: 121kt<V_{at}<141kt. [1]

For departures, the design bank angle is chosen depending on the altitude, as specified in DOC 8168 VOL II, while for arrivals the bank angle was assumed to be 25°.

The models used to calculate the new latitude and longitude points assumes a spherical earth that ignores ellipsoidal effects. This is sufficiently accurate for small range calculations, but for the calculation of the distance between two geographical co-ordinates: (lat1,long1) and (lat2,long2) the Haversine formula (equation 2) was used.

$$d=R.2.\mathrm{atan2}\left(\sqrt{a},\sqrt{1-a}\right) \tag{2}$$

where R is the earth's radius and 'a' is given by equation (3):

$$a=\sin^2(\Delta lat/2)+\cos(lat1).\cos(lat2).\sin^2(\Delta long/2) \tag{3}$$

To find the initial heading between two points, equation (4) was used. Since the heading varies when moving from one geographical co-ordinate to another, the final bearing was found by taking the end point as the initial point using the same formula.

$$\theta=\mathrm{atan2}\begin{pmatrix}\sin(\Delta long).\cos(lat2)\ , \\ \cos(lat1).\sin(lat2)-\sin(lat1).\cos(lat2).\cos(\Delta long)\end{pmatrix} \tag{4}$$

When the distance and bearing from a defined geographical waypoint specified in the AIP was known, the new waypoints specified in latitude and longitude for the proposed SIDs and STARS were found using equation (5):

$$\begin{aligned} Lat2&=\mathrm{asin}\begin{pmatrix}\sin(lat1).\cos(\frac{d}{R}) \\ +\cos(lat1).\sin(\frac{d}{R}).\cos(\theta)\end{pmatrix} \\ Lon2&=lon1+\mathrm{atan2}\begin{pmatrix}\left(\sin(\theta\right).\sin(\frac{d}{R}).\cos(lat1)\ , \\ \cos(\frac{d}{R})-\sin(lat1).\sin(lat2)\end{pmatrix}\end{aligned} \tag{5}$$

2.3 RNAV and RNP navigational methods

Aircraft equipped with RNAV capability can fly routes on any desired path within the coverage of the ground based or space based navigational aids. The required navigational performance determines the tolerance accuracy for operations within a defined airspace. RNAV equipped aircraft have flight management systems that allow aircraft to fly the pre-described or intended routes with increased accuracy. Furthermore, the RNAV concept does not require aircraft to fly over specific radio navigational beacons, allowing more direct routing paths and thus lower track miles to be flown to landing. Precision RNAV (P-RNAV) capability is today recommended within the terminal airspace of ECAC states, and this is defined as meeting the requirements of RNP 1 [5].

RNP-RNAV routes are predictable and repeatable to the declared accuracy and probability, that is, the across track tolerance (ATT) and the cross track tolerance (XTT) are guaranteed equal to the RNP value on 95% of the time.

Waypoints are used to define RNAV routes and the flight paths flown by aircraft. Waypoints, which can be either fly-by or fly-over, are currently defined internationally according to the WGS-84 standard co-ordinates [5]. The designer of terminal procedures has to specify whether an aircraft should change its heading either by flying by a waypoint or by flying over the waypoint before starting the turn to the next route leg. For fly-by waypoints, the FMS calculates the start of the turn, known as the anticipation distance, depending on a number of factors, including wind and speed of the aircraft. The fly-by waypoint is preferred to the fly-over waypoint since the track followed by the aircraft is more predictable. In fly-over turns, FMS trajectories will vary with wind, speed and bank angle limitation, hence being non-predictable and should be avoided as much as possible.

Modern flight management systems (FMSs) are equipped with databases that are coded using the ARINC 424 standard [7] and are capable of flying RNAV routes. The path terminator concept used in ARINC 424 permits the coding of Terminal Area Procedures into the FMS. The path and terminator are assigned a two-letter code, which defines a specific type of flight path along a segment of a procedure and a specific type of termination of that flight path.

To verify that the RNAV procedures can be coded in the FMS, RNAV routes have been designed to be compatible with the database path terminators defined in DOC 8168 VOL II . These path terminators define specific ground tracks, based on the assumption that aircraft approved to fly RNAV procedures have the capability to maintain consistent tracks through the use of appropriate ARINC 424 path terminators, or their equivalent. When designing the SIDs and STARs attention was given to ensure that the paths chosen could be translated into a sequence of ARINC 424 legs from take-off until the en-route structure is joined and from the point where the aircraft leaves the en-route segment until the end of the arrival procedure marked by the initial approach fix (IAF), at which point the approach segment is initiated.

Many aircraft are currently equipped with RNAV systems that are only capable of using a sub-set of the available ARINC 424 Path Terminators. The basic and recommended Path Terminator is the Track between Fixes (TF) because all FMS implementations can perform it. A TF route is defined by the geodesic path between two waypoints, with the first waypoint being the termination waypoint of the previous segment or an initial fix.

For departures, turns have been designed using Radius to Fix (RF) legs, due to the flexibility and accuracy in the design of the procedure tracks. However, these are only compatible with RNP-equipped aircraft [8]. In procedure design manuals [5], it is also recommended that for course changes greater than 30°, RF legs should be used. The RF segment is a circular path defined by an initial arc that is, in turn, defined by the terminating waypoint of the previous segment, the turn centere, turn radius and the tangential fly-by way point at the end of the turn.

The Course to a Fix (CF) was also used to describe the initial leg of the departure procedure. The CF is effective in constraining the track dispersion and keeps the course heading in the direction of a waypoint.

2.4 Minimum stabilization distance between two fly-by waypoints

To prevent placing turning way points too close to each other, which would result in the aircraft being unable to fly the desired trajectory accurately, waypoint positions were determined using the minimum length of a segment specified for fly-by waypoints in DOC 8168 VOL II.

The minimum distance between waypoints is influenced by the extent of course change and the type of transitions at the end of each leg. Also, in the location of the waypoints, it was ensured that the maximum track change between different legs will be smaller than 120°, in line with the Guidance Material for the Design of Terminal Procedures for Area Navigation [5].

In this work only waypoints with fly-by turns were used. The anticipation distance is defined as the distance from the turn fix to the start and end points of a fly-by turn, calculated by the FMS depending on the radius of the turn r and the course change in degrees θ, at which the aircraft starts the turn to intercept the next leg in a tangential manner as shown in Fig. 2 [8]. This distance is found using equation (6):

$$L_1 = r \times \tan\left(\frac{\theta}{2}\right) \quad (6)$$

For RNP procedures, where aircraft can make bank angle variations to compensate for wind effects such as to follow the pre-determined trajectory with the navigation accuracy related to the RNP, equation (7) is used to find the radius r in NM (as shown in Fig. 2), where V is the maximum true airspeed in knots, V_W is the maximum wind speed in knots and θ is the maximum bank angle in degrees [6].

$$r = \frac{(V+Vw)^2}{68626.\tan(\theta)} \quad (7)$$

The roll anticipation distance, is the horizontal distance flown by the aircraft when adjusting the bank angle to roll in or out of a turn. For a fly-by turn as shown in Fig. 2 this is calculated using equation (8):

$$L_2 = \frac{c(V+V_w)}{3600} \tag{8}$$

where c is the bank establishment time, normally taken as 5sec.

If the second turn is in the opposite direction to the first turn, then the minimum leg length between two fly-by turns is the sum of the turn anticipation distances calculated using equation (6) for both turns, and the roll anticipation distance between the first and second turn.

However, if both turns are in the same direction, it could be argued that the minimum leg may be reduced by reducing the roll-out distance for the first turn and the roll-in distance for the second turn.

The designed SIDs and STARs were focused within the terminal area of Malta shown in Fig. 1. RNP-RNAV departures and RNAV arrival routes were designed to reduce the number of track miles flown during arrivals and departures from Malta. This was achieved by utilizing more direct routing paths, which is facilitated by the flexibility offered by the RNAV design methods [2].

3 The SIDs and STARs proposed

In this paper, revised SIDs and STARs for runway 13 are proposed. Currently conventional SIDs are available for this runway, but no arrival routes are specified. In April 2012, the T-bar concept was introduced for runways 13 and 31, where aircraft are directed by ATC to one of the initial approach fixes when approaching Malta [2].

3.1 Departures for runway 13

In line with the recommendations of Doc 8168, a straight departure using runway heading until reaching a height of 394ft above the Departure End of Runway (DER) was retained. The procedure design gradient was taken as 7%, against the 3.3% recommended in procedure design manuals. This was in order to enable the start of a fixed radius turn as early as possible. The climb gradient chosen is easily achieved by category C aircraft similar to the B737 and A320 families of aircraft operating under normal conditions.

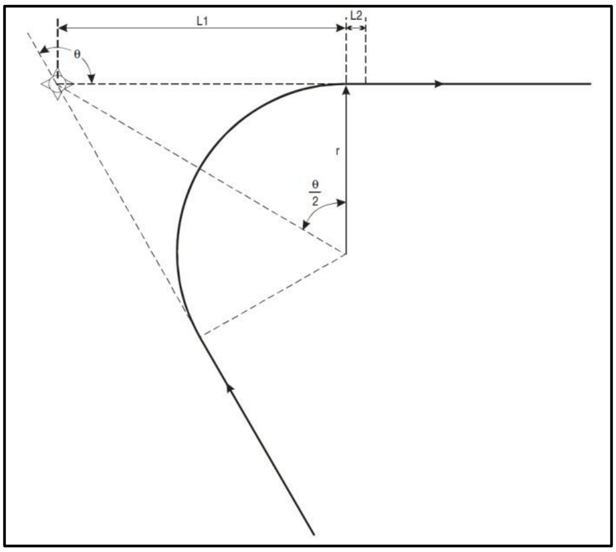

Fig. 2. Fly-by turn [6]

Since RNP-1 was assumed, a 1NM across track tolerance was allowed for when locating the first fly-by-waypoint on the extended runway center-line which initiates a fixed radius turn. Consequently, the location of this waypoint was identified using the runway length, the distance required to reach 394ft above the DER assuming a 7% climb gradient plus an extra 1NM to cater for the RNP-1 tolerances. This placed the waypoint at 7.1km from the threshold of runway 13. This waypoint has been given the name WENDY. Using equation (5) to find a geographical co-ordinate given distance and bearing, WENDY was consequently placed at N35° 48’ 48’’ E014° 32’14’’, as depicted in Fig. 3. The course heading to the waypoint from departure is 132° Magnetic.

Fixed radius left hand and right hand turns commencing at WENDY were designed according to the equations presented in Section 2.4. For departures, DOC 8168 specifies that a turn should be constructed using the design indicated air speed for final approaches +10%, and assuming a 30kts omni-directional wind. As the routes have been designed for category C aircraft, the departure speed of 264KIAS was adopted [5]. Given that LMML runway elevation is 300ft above sea level, the aircraft will nominally have reached 1119 ft by WENDY assuming a climb gradient of 7% from the end of runway 13. The design bank angle allowed between 1000 ft and 3000 ft is of 20°. Hence, the design of the RF turn was constructed using a radius of 3.72NM calculated using equation (7). WENDY is therefore the initial fix of the RF leg. A number of waypoints on the turns which tangentially connect to the exit points through a TF leg, were defined.

An RF turn is normally specified by the radius, the center of the turn and the tangential point at the end of the turn. To define these co-ordinates, geometrical mathematics using the WGS-84 co-ordinates was required. The WGS-84 co-ordinates were transformed to the UTM co-ordinate system to allow the use of Cartesian geometry to define these points. The transformed way points were specified by x and y co-ordinates in metres. This co-ordinate system divides the earth in 60 zones, each of 6 degrees longitude wide and extends from a latitude of 80° South to 84° North. In each zone, the Cartesian co-ordinate system can be utilized. The location of Malta and the routes designed all lied within zone 33 [9].

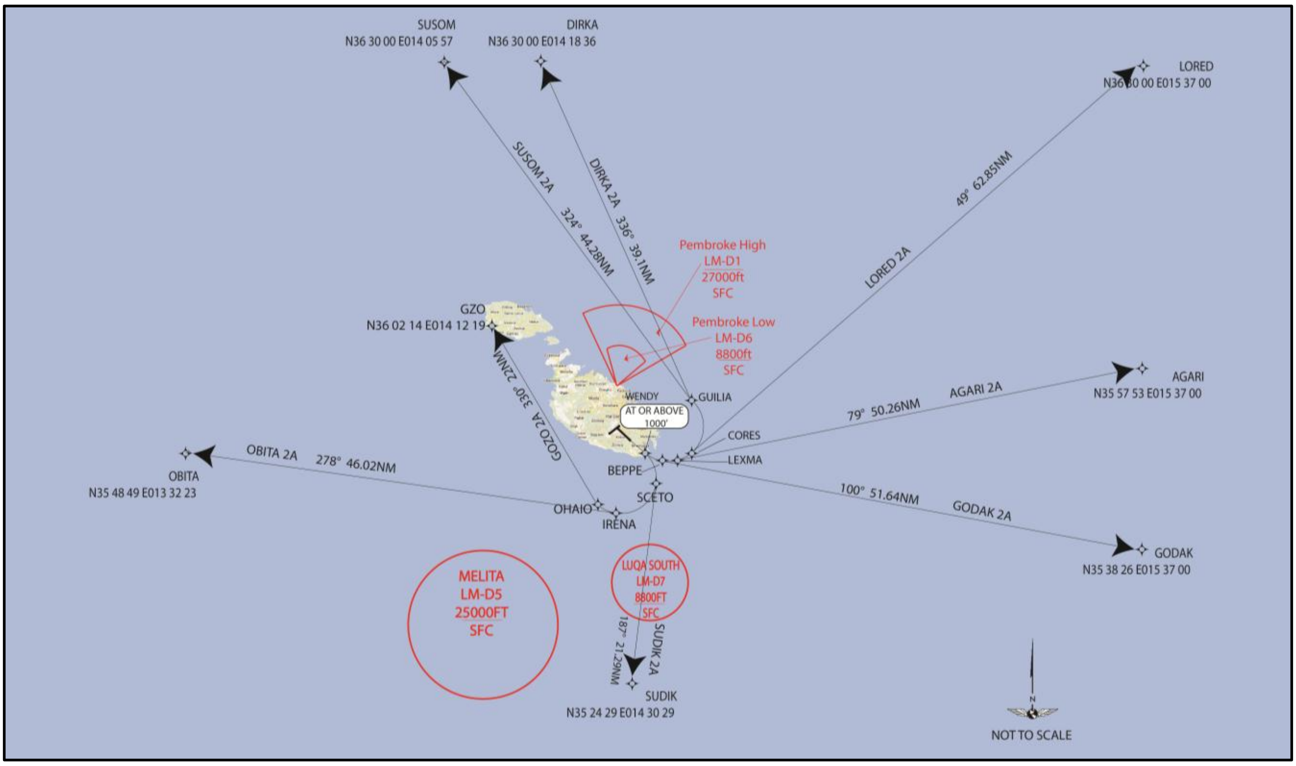

Figure 3. The proposed runway 13 RNP-1 departures for LMML

The RF center of the turns were located using right angle triangle geometry with the line joining WENDY to the runway's threshold. The two centers are located at N35°51'34.192'' E14°35'19.130'' and N35°46'1.891'' E14°29'9.264''.

The tangential fly-by way points at the end of the turns were located by finding the intersection of the circle equation of the turn and the equation of the tangential line joining the exit point to the RF circle followed by the aircraft.

The existing conventional SID for runway 13 has certain altitude constraints and these were respected when designing the RNP departure route. One altitude constraint that was respected is the altitude required to be achieved for right turns to OHAIO. The West coast of Malta is used for light aircraft training, consequently, commercial aircraft following a departure to GOZO specified by GOZO 2A in

Fig. 3, are required to reach an altitude of at least 2500ft by OHAIO to ensure vertical separation between light aircraft and commercial aircraft. Light aircraft are kept around 1500ft in the area.

Apart from modifying the existing departure routes to support RNP departures, two new departures were also developed. After analyzing the terminal traffic flow at LMML between January 2010 and October 2011, the most common routes were found to be via ADEXI, DILIN and NELDA. These waypoints are not shown in Fig. 3 as they are further north than the area shown. For DILIN and NELDA aircraft are directed via the SUSOM 2A and DIRKA 2A departures (Fig. 3) respectively. The latter waypoints lie within the Maltese terminal area and connect to DILIN and NELDA respectively through published en-route paths. For departures to ADEXI, aircraft are routed via GOZO 2A. This routing does not introduce any appreciable performance penalty to the departing aircraft, since only a small change in heading is required to join from GOZO to SOPIR en-route to ADEXI. Departures to DILIN and NELDA should follow the GOZO 2A SID only when LM-D1 is active, since this offers a performance penalty on the track miles flown.

The designed RNP departure routes were converted to the path terminators specified by PANS-OPS DOC 8168 Vol II and ARINC 424, details of which are presented in Table 2. This RNAV procedure description is an essential part for database coding of flight management computers [11].

SID	SEQUENCE NUMBER	WAY POINT	PATH TERMINATOR	FLY-OVER	TURN	ALTITUDE CONSTRAINT	SPEED CONSTRAINT	RADIUS (NM)	CENTRE OF TURN	TRACK (°*M*)	DISTANCE (NM)
GOZO 2A	1	WENDY	CF	NO	-	1000+	-	-	-	132.29°	1.92
	2	OHAIO	RF	NO	R	2500+		3.72	N35°46’1.89’’ E14°29’9.26’’	-	11.69
	3	GZO	TF	NO	R	-	-	-	-	330°	22
SUDIK 2A	1	WENDY	CF	NO	-	1000+	-	-	-	132.29°	1.92
	2	SCETO	RF	NO	R	-	-	3.72	N35°46’1.89’’ E14°29’9.26’’	-	3.56
	3	SUDIK	TF	NO	-	-	-	-	-	187°	21.29
OBITA 2A	1	WENDY	CF	NO	-	1000+	-	-	-	132.29°	1.92
	2	IRENA	RF	NO	R	-	-	3.72	N35°46’1.89’’ E14°29’9.26’’	-	9.5
	3	OBITA	TF	NO	-	-	-	-	-	278°	46.02
GODAK 2A	1	WENDY	CF	NO	-	1000+	-	-	-	132.29°	1.92
	2	BEPPE	RF	NO	L	-	-	3.72	N35°51’34.19’’ E14°35’19.13’’	-	2.07
	3	GODAK	TF	NO	-	-	-	-	-	100°	51.64
AGARI 2A	1	WENDY	CF	NO	-	1000+	-	-	-	132.29°	1.92
	2	LEXMA	RF	NO	L	-	-	3.72	N35°51’34.19’’ E14°35’19.13’’	-	3.49
	3	AGARI	TF	NO	-	-	-	-	-	79°	50.26
LORED 2A	1	WENDY	CF	NO	-	1000+	-	-	-	132.29°	1.92
	2	CORES	RF	NO	L	-	-	3.72	N35°51’34.19’’ E14°35’19.13’’	-	5.39
	3	LORED	TF	NO	-	-	-	-	-	49°	62.85
DIRKA 2A	1	WENDY	CF	NO	-	1000+	-	-	-	132.29°	1.92
	2	GUILIA	RF	NO	L	-	-	3.72	N35°51’34.19’’ E14°35’19.13’’	-	11.69
	3	DIRKA	TF	NO	R	-	-	-	-	336°	39.1
SUSOM 2A	1	WENDY	CF	NO	-	1000+	-		-	132.29°	1.92
	2	GUILIA	RF	NO	L	-	-	3.72	N35°51’34.19’’ E14°35’19.13’’	-	11.69
	3	SUSOM	TF	NO	R	-	-	-	-	324°	44.28

Table 2 The FMC database coding reference for RNP-1 departures from LMML, runway 13.

3.2 Arrivals on runway 13

Doc 8168 states clearly that arrival routes (STARs) should be simple, easily understood and contain the least possible number of way points.

In April 2012, T-bar approaches were issued by Transport Malta for intersecting the ILS for runways 13 and 31. For runway 13, NEDIT was identified as the intermediate fix, while LANEL, SOMIB and GZO were identified as the initial approach fixes. These were incorporated in the proposal of the new arrival routes, also because they support the targets of this work.

The RNAV TF leg was used to directly route the entry points found at the boundary of Malta’s terminal area to one of the initial approach fixes. This provided the connection between northerly way points and NEDIT for straight in approaches, right hand circuits via SOMIB and left hand circuits via LANEL. The TF legs were directed within the 180° capture window of the initial approach fixes to avoid aircraft needing to perform procedure turns. Aircraft arriving from UPLIT, SOPIR, EKOLA, SUSOM and DIRKA will be directed to NEDIT; those arriving from MOLAM, DORAT, OBITA, KOSET and SUDIK via SOMIB and those arriving from DIRAK via TIMPA and SOMIB (Fig. 4).

Arrivals from LORED, AGARI AND GODAK are routed via LANEL when LM-D1 is inactive. However, when this danger region is active, AGARI and GODAK arrival paths will be directed to the initial approach fix DIECI.

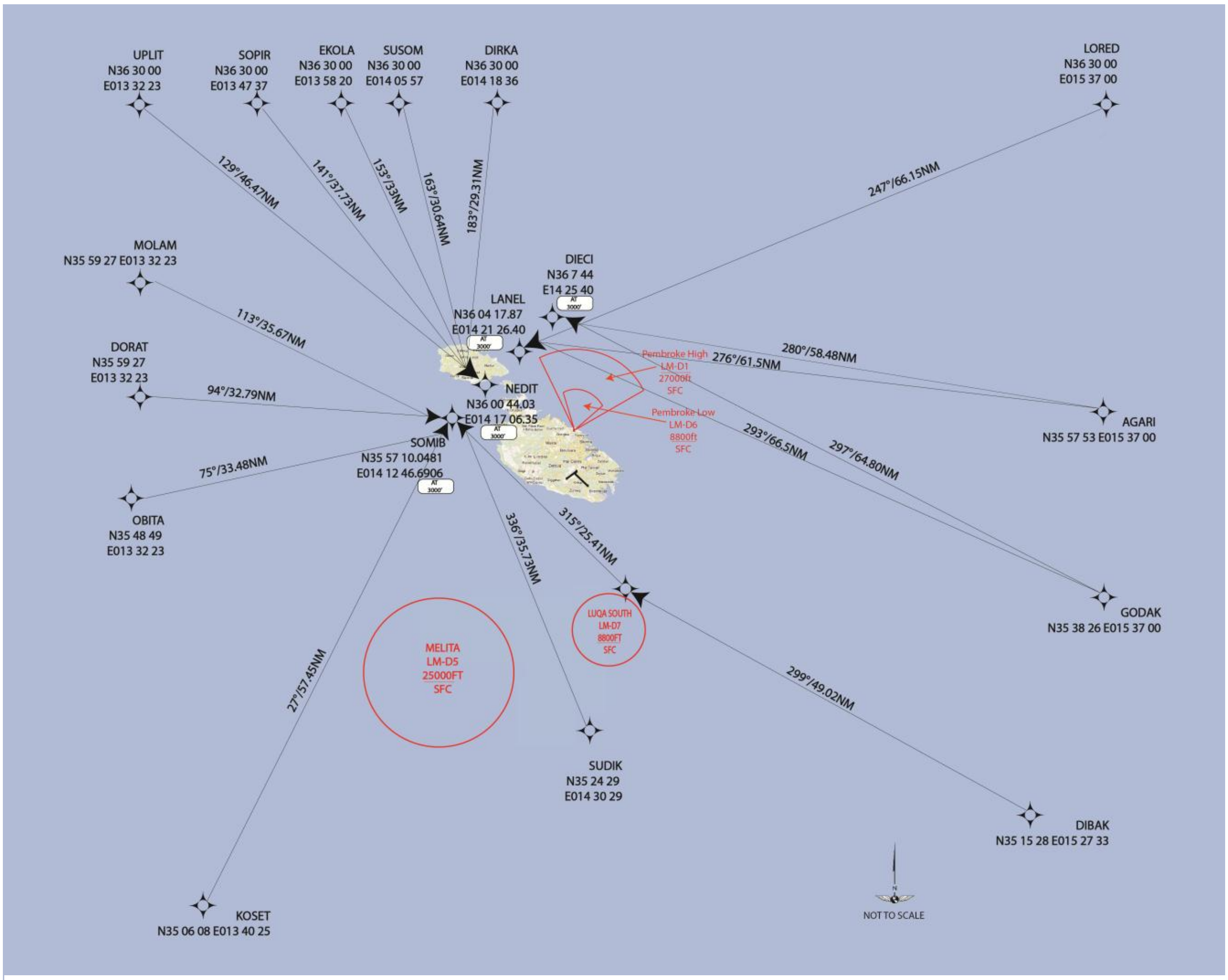

Fig. 4. The proposed runway 13 RNAV arrival for LMML

4 Conclusion and Future Work

This paper has presented the methodologies adopted for the development of revised SIDs, STARs, and associated procedures that are sensitive to the environmental impact from departing and arriving aircraft at Malta International Airport. A review of the current local ATM system was first performed, followed by the identification of the necessary design parameters for category C aircraft and geographical co-ordinate system to be used in the design of the procedures. RNAV and RNP navigational methods were then adopted together with a derived minimum stabilization distance between two fly-by waypoints to design the new procedures. The revised SIDs and new STARs for runway 13 were finally presented, analyzed and discussed in depth.

The work has formed the basis for the development of a complete ground-based optimization tool which can be used by the ATC in conjunction with pilots such as to find the optimal routes which the aircraft should follow to minimize carbon emissions and consume less fuel. The route is divided in two profiles, one in the vertical plane and the other in the horizontal plane. The lateral profile will be defined by one of the revised SIDs or STARS, while the vertical profile will be calculated by a vertical profile optimizer and it will depend on a number of factors such as the aircraft's weight, the wind forecast, and the aircraft type amongst others. The vertical path optimizer will return the thrust, flight path angle and the speed-altitude schedule of the aircraft for particular phases of flight when following a particular SID or STAR. The final three-dimensional trajectories will result from the overlaying of the optimal vertical profile trajectories on top of the waypoints defined by the SIDs or STARs.

References

[1] Aircraft Operations, Procedures for Air Navigation Services, Volume 1, Flight Operations. s.l. : International Civil Aviation Organization, 2006.

[2] MALTA Aeronautical Information Publication(AIP) . 4th. s.l. : CIVIL AVIATION DIRECTORATE, TRANSPORT MALTA, 2012.

[3] RNAV PROCEDURE DESCRIPTIONS. s.l. : International Civil Aviation Organization.

[4] Terpstra, Jim. RNAV (GNSS) Procedures. 2009. http://www.lima.icao.int/meetprog/2009/SAMIG4/presentacion%20jeppesenPeru%20ICAO%20PBN%202009.pdf.

[5] Eurocontrol. Guidance Material for the Design of Terminal Procedures for Area Navigation (DME/DME, B-GNSS, Baro-VNAV & RNP-RNAV). s.l. : Eurocontrol, 2003.

[6] Aircraft Operations,Procedures for Air Navigation Services,Volume II, Construction of Visual and Instrument Flight Procedures. 5th. s.l. : International Civil Aviation Organization, 2006.

[7] Introduction to ARINC 424. [Online] 2005.

[8] Guidance material concerning criteria on required navigation performance authorization required (RNP AR) Procedure Design, DOC 9905. s.l. : International Civil Aviation Organization, 2008.

[9] http://www.rcn.montana.edu/resources/tools/coordinates.aspx?nav=11&c=UTM&md=83&mdt=NAD83/WGS84&z=33&e=468718&n=3979638&h=N.

[10] Required Navigation Performance (RNP) 1 Departure Procedure (DP). s.l. : Federal Aviation Administration, 2012.

[11] Prats, X., Quevedo, J., Puig, V., Trajectory Management for Aircraft Noise Mitigation. ENRI International Workshop on ATM/CNS, 2009.

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