RNAV PROCEDURE DESIGN FOR BUDAPEST AIRPORT

Infrastructures de transport aeri

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INTRODUCTION:

The aim of the project is to review , so to re-design a PBN non-precision approach instrument approach procedure (navigation specification RNP APCH - LNAV).

The project will be developed drawing the approach procedures and the associated protection areas in a topographic chart, considering aircraft categories and all the other necessary requirements.

In our case, these specific requirements are :

- Ensure correct distance between waypoints (MSD)
- Ensure correct speed limitations
- Ensure correct altitudes published
- Ensure correct LNAV minima published.
- Ensure correct analysis of the visual segment (VSS)
- Ensure correct TAA published
- Ensure correct chart format and content
- Cartography and the artificial obstacles published in the map should be taken into account in the obstacle assessment.
- Appropriate vegetation safety margin should be added to the terrain elevation.

Minimum Stabilization Distance :

In order to check if the RNAV approach procedures for the Runway 13R at Budabest Airport we will analyse if the Minimum Stabilization Distance [MSD] between waypoints is met.

We willl analise the MSD for the procedures that involve turns and those are the ones that start at the IAFs GIGAN and KESID.

To ensure a correct distance between waypoints we must meet the following criteria:

$$\text{Initial Approach Segment Length} \geq MSD_1 + MSD_2$$

$$\text{Intermediate Segment Length} \geq 2NM + MSD_2$$

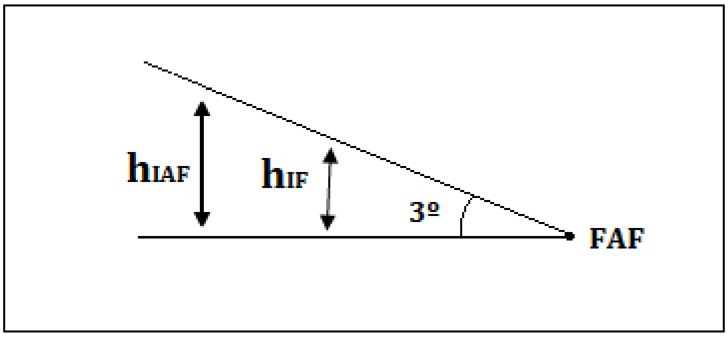
As a maximum turn angle we will take 110º and we will be using Non-SI units in our study.

Following the guidance of the PANS-OPS document we find that the bank angle considered will be 25º (**Table III-2-3-7**) and that the speed limitation, since we consider airplanes up to CAT D, is 250kt of IAS (**Table III-2-1-9**).

However according to our document (**Table III.2.19**) we need to have the speed in TAS so we will need to convert the 250kt of IAS to TAS:

$$TAS = \frac{IAS * 171233[(288 + VAR) - 0.00198h]^{0.5}}{(288 - 0.00198h)^{2.628}}$$

Where VAR will be 15ºC, IAS is 250kt and h is the height in feet that we will compute for the IAFs to get the MSD1 and for the IF to get MSD2:



hKESID = hFAF +[tan(3º)*22224]=2079.11m

hKESID =6821.227ft

hGIGAN = hFAF +[tan(3º)*23705.6]=2156.76m

hGIGAN =7075.984ft

hIF = hFAF +[tan(3º)*11112]=1496.755m

hIF =4910.613ft

Once we got the heights at the IAFs and at the IF we can use the formula we previously found to convert IAS to TAS:

TAS KESID= 284.37kt

TAS GIGAN = 285.498kt

TAS IF = 276.108kt

Now that we have the maximum speeds in TAS we can use the tabulated MSD (Table III.2.19) for which we need the angle of turn (110º) and the speed. Then we interpolate and get the following equation:

MSD=0.025*TAS-3.1

When we use the equation and considering that the initial segment starting at KESID is 6NM long, the intial segment staring at GIGAN is 6.8NM and the intermediate segment is 6NM we get the following results:

MSD1(KESID)= 4NM → MSD1 + MSD2 = 7.8NM

The distance is grater than 6NM so the requirements are **not** met.

MSD1(GIGAN)= 4.03NM → MSD1 + MSD2 = 7.83NM

The distance is grater than 6.8NM so the requirements are **not** met.

MSD2= 3.8NM → 2NM + MSD2 = 5.8NM

The distance is not grater than 6NM so the requirements are met.

When this chart was designed the may have not taken 110º as a maximum turn angle that is why the Minimum Stabilization Distance might be correct for they cosiderations but in our case we may solve this changing the speed limitations.

We must change the IAS max for approaches up to 110º:

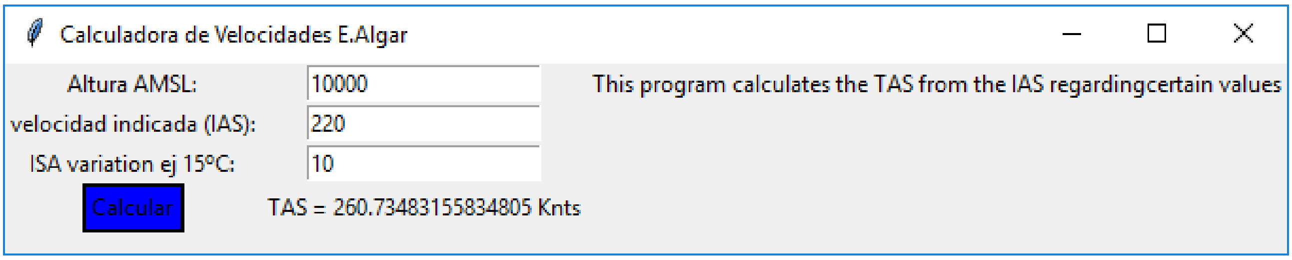
MSD1(KESID)= 6NM-MSD2 = 2.2NM → TAS=212kt → IASmax=186kt

MSD1(GIGAN)= 6.8NM-MSD2 = 3NM → TAS=244kt → IASmax=220kt

TAS calculator:

In order to make fast and precise calculations we programmed a calculator using python 3.6:

```
fromtkinterimport *


def calculadora():
TAS = eval(IAS.get()) * 171233 * (((288 + eval(VAR.get())) - 0.00198 * eval(h.get())) ** 0.5) / (288 - 0.00198 * eval(h.get())) ** 2.628
resultado.set('TAS = ' + str((TAS))+ ' Knts')

ventana = Tk()
ventana.minsize(400,100)
ventana.title('Calculadora de VelocidadesE.Algar')

etiqueta1 = Label(ventana, text='Altura AMSL:')
etiqueta1.grid(row=0, column=0)
h = StringVar()
cuadro1 = Entry(ventana, textvariable=h)
cuadro1.grid(row=0, column=1)

etiqueta2 = Label(ventana, text='velocidad indicada (IAS):')
etiqueta2.grid(row=1, column=0)
IAS = StringVar()
cuadro2 = Entry(ventana, textvariable=IAS)
cuadro2.grid(row=1, column=1)

etiqueta3 = Label(ventana, text='ISA variation ej 15ºC:')
etiqueta3.grid(column=0, row=2)
VAR = StringVar()
cuadro3 = Entry(ventana, textvariable=VAR)
cuadro3.grid(row=2, column=1)

resultado = StringVar()
etiqueta4 = Label(ventana, textvariable=resultado)
etiqueta4.grid(row=3, column=1)

boton = Button(ventana, text='Calcular', bg='blue',relief=SOLID, command=calculadora)
boton.grid(row=3, column=0)

description = Label(ventana, text='This program calculates the TAS from the IAS regarding\
certain values')
description.grid(column=3, row=0)
ventana.mainloop()
```



Obstacle clearance altitude/height (OCA/H):

Approach phase:

In order to compute the minimum altitude per segment we compute the sum of the segment MOC plus the altitude of the highest obstacle:

$$OCA_{min\,seg} = MOC + Alt_{highest\ obstacle}$$

The MOCs for different stages of the approach are:

Segment	MOC
Initial approach	984 ft
Intermediate approach	984 ft
Final approach	246 ft
Initial miss approach	246 ft
Intermediate miss approach	98 ft
Final miss approach	164 ft

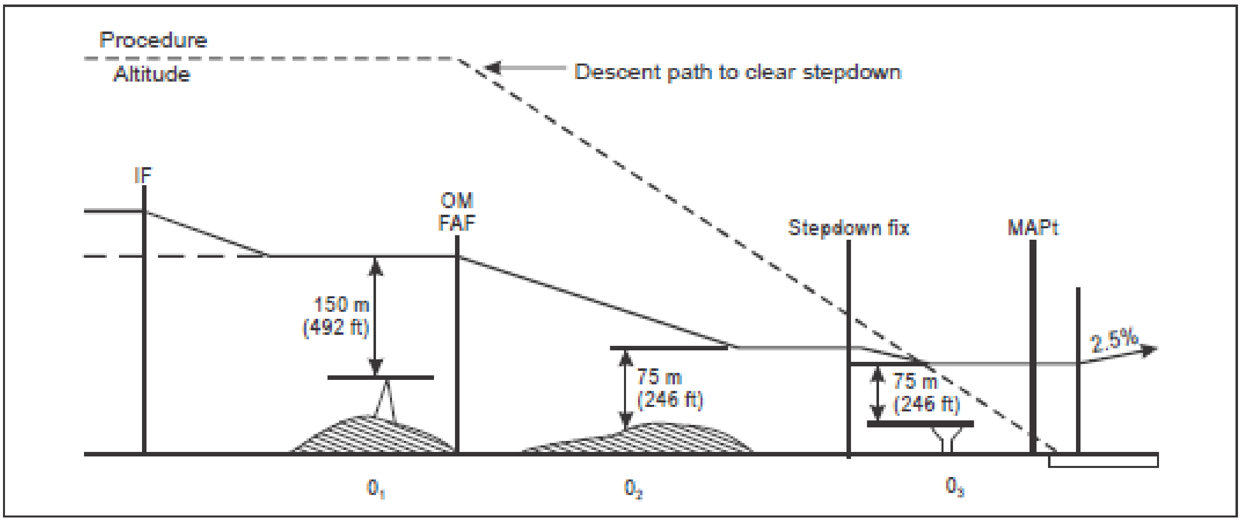


Fig 2.1: *example of the vertical profile using a LOC app (Source : [2])*

However, we also have to take into account the protection areas OCAs which can be calculated by multiplying the altitude of the obstacle with its percentage with respect to its position in the protection area:

$$OCA_{min\,seg} = MOC + Alt_{highest\ obstacle} \cdot (distance\% * 0.01)$$

If the value obtained is higher than the OCA in the main area, we will use the OCA of the protection area in order to maintain the safety levels.

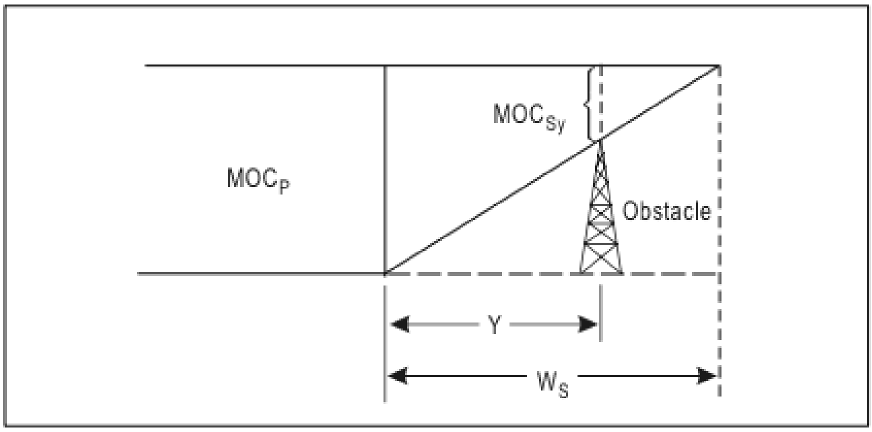


Fig 2.2: *OCA in the secondary area (Source : [2])*

Missed Approach:

The missed approach climb starts at the SOC (Start of Climb point) aircraft have to ensure a minimum climb gradient of 2.5 º and the procedure has to ensure that aircraft will be over the obstacles at height of at least 30m above them.

If these requirements are not meet and the SOC is not able to be modified, the only way the approach can be designed is by rising the OCA.

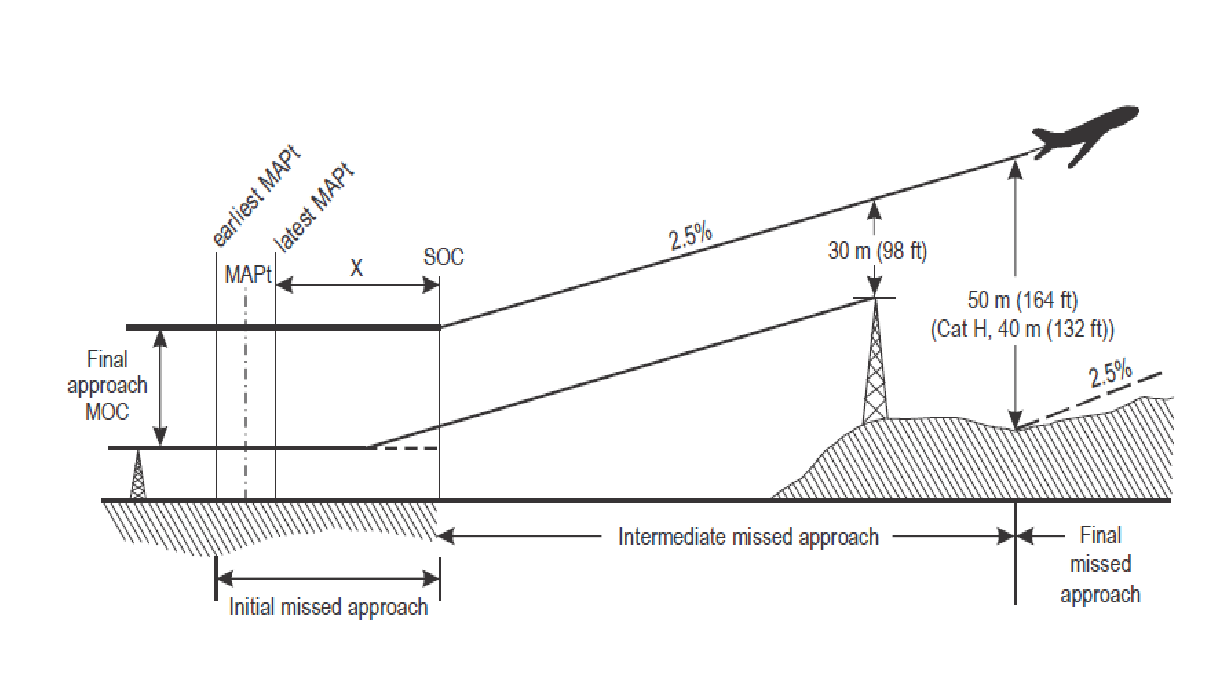


Fig 2.3. *Sketch of the initial missed approach phase and its O.C. (Source : [2])*

In our experiment, we obtain the following results, however first, we would like to mention that in the intermediate segment we found an OCA higher in the protection area than in the main segment.

Our final results are:

Segment	Max obstacle altitude (ft)	OCA (ft)
Initial app	2483.6	3480
Intermediate app	1608.9	2600
Final app	702.1	950
Initial miss app ✈	194	440

✈ we Will go further in the analysis of the miss approach OCA

LNAV MINIMA :

In our analysis of the chart we will check if the altitudes published and the LNAV minima are correct. To be able to do this first we need to draw the protection areas in our map to see we position of the obstacles and analyse altitudes.

Since we have three IAFs we will have a straight-in approach segment, starting at the IAF VATOR and two IAFs (KESID and GIGAN) that will involve a turn construction.

Straight-in Segment:

If we look for a reference in PANS-OPS we will find a schematic to guide us:

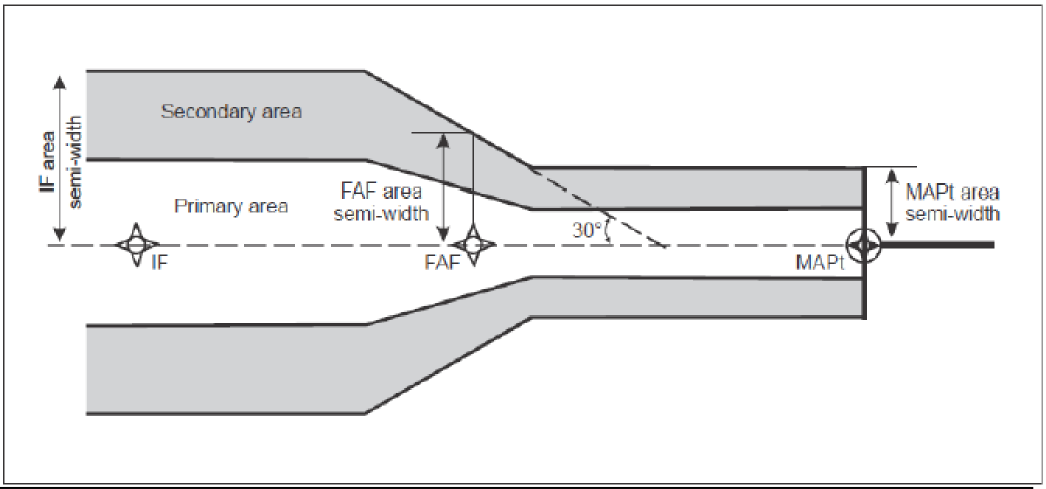
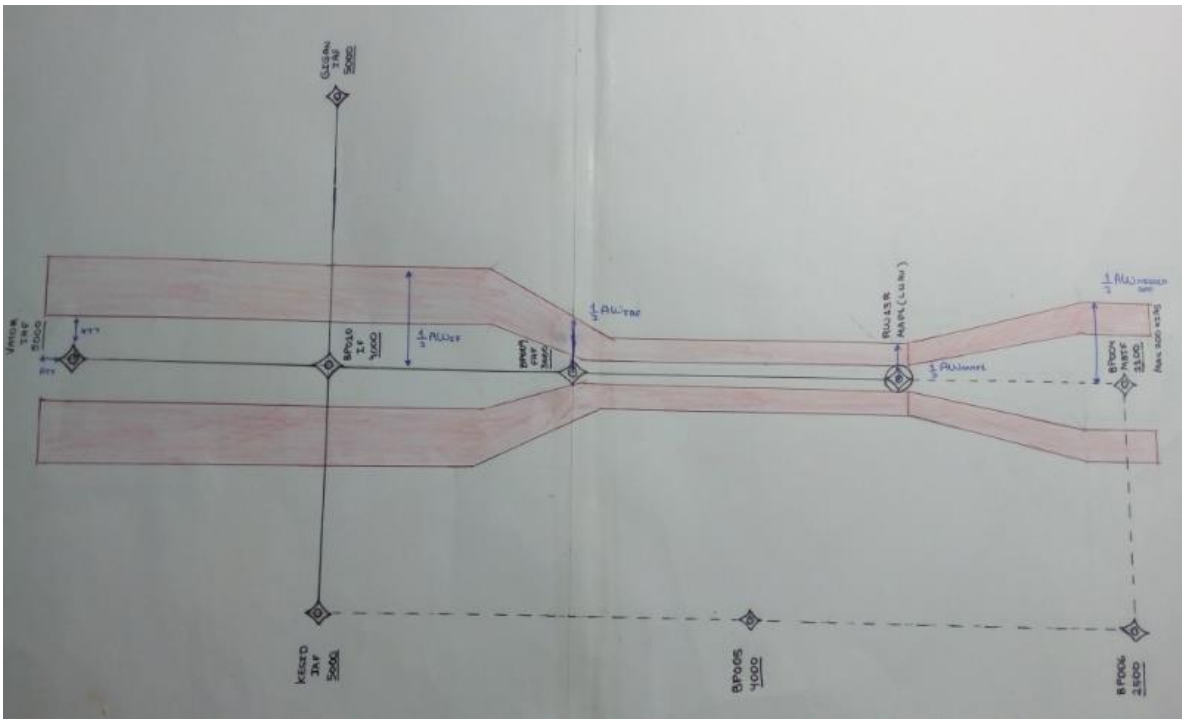


Figure 3.1 (Source : [3])

With this schematic and the information that we obtain about the along-track tolerance (ATT), the cross-track tolerance (XTT) and the half area width for each segment(1/2AW) that we obtain also in the document (Table III.1.2.14) we can draw the protection areas for the straight-in segment:



Turn Construction:

If we look for a reference in PANS-OPS we will find a schematic to guide us:

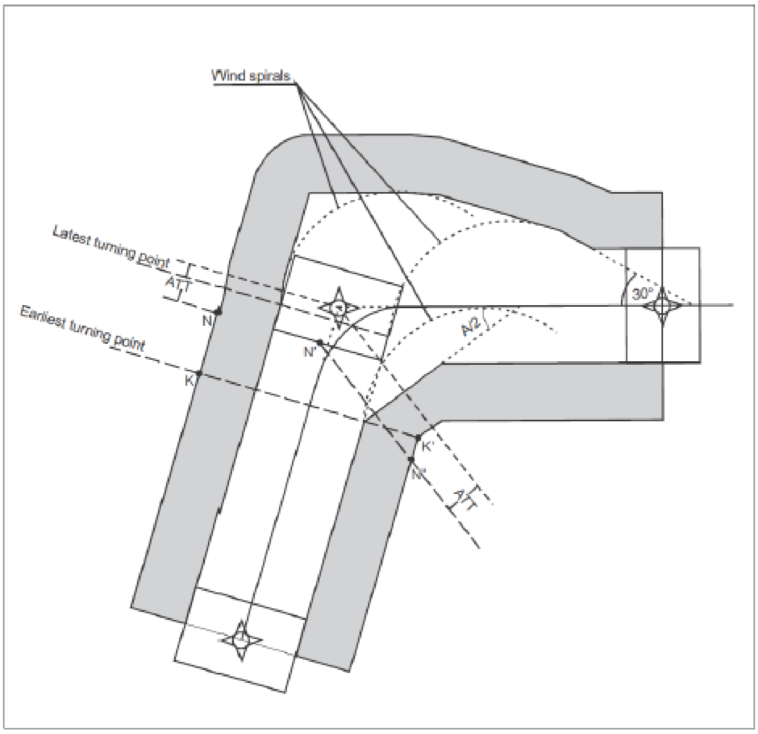


Figure 3.2 *(Source : [3])*

To draw the wind spirals that determine the turn, first of all we will obtain the rate of turn which can be computed with the following formula:

$$\boldsymbol{R} = \frac{3431 * Tan(\alpha)}{\pi V}$$

Where α is the bank angle which is 25º and V is the TAS in kt which is 277kt.

> **R=1.84degrees/second**

Now we need to find the radius of turn which can be computed with the following formula:

$$\boldsymbol{r} = \frac{V}{20\pi R}$$

Where R is the rate of turn which is 1.84 degrees/second and V is the TAS in kt which is 250kt.

r=2.39NM

Eventually we can draw the wind spiral that is the model of the wind deviation effect in the turn. The wind spiral consists on a series of circles of increasing radius as shown on the schematic below:

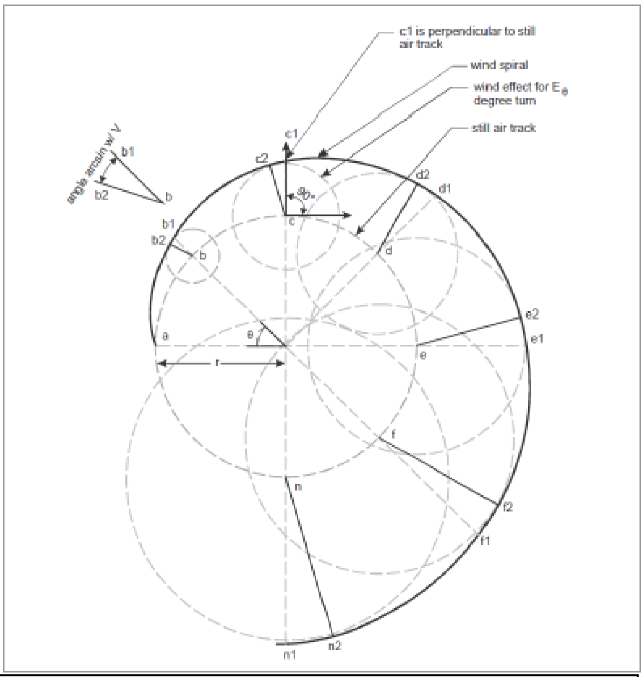


Figure 3.3 *(Source : [3])*

The interval among circles witth be 45º and the radius of each circle will be computed with the following formula:

$$\boldsymbol{E\theta} = \frac{\theta}{R} * \frac{w}{3600}$$

Where θ is the angle, R is the rate of turn which is 1.84 degrees/seconds and w is the wind speed which according to PANS-OPS (Table I.2.3.1) is 30kt.

>**E45º**=0.2NM

>**E90º**=0.4NM

>**E135º**=0.61NM

>**E180º**=0.815NM

>**E225º**=1.019NM

>**E270º**=1.223NM

Once we have all the data we can draw the wind spiral that can be seen below:

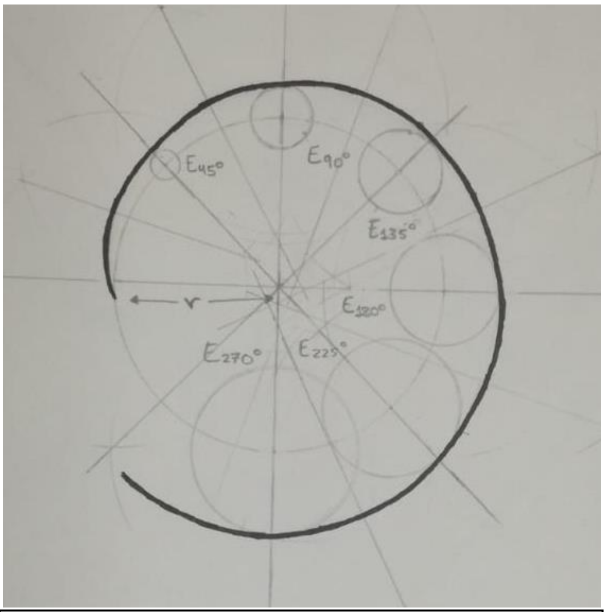


Figure 3.4 *(Source : [3])*

With wind spiral and the information about the ATT, XTT and 1/2AW we obtain in PANS-OPS (Table III.1.2.14) we only need to find the Earliest Turning Point (ETP) and the Latest Turning Point (LTP) which can be obtained with the formulas below:

$$\boldsymbol{ETP} = ATT + [rTan\left(\frac{A}{2}\right)]$$

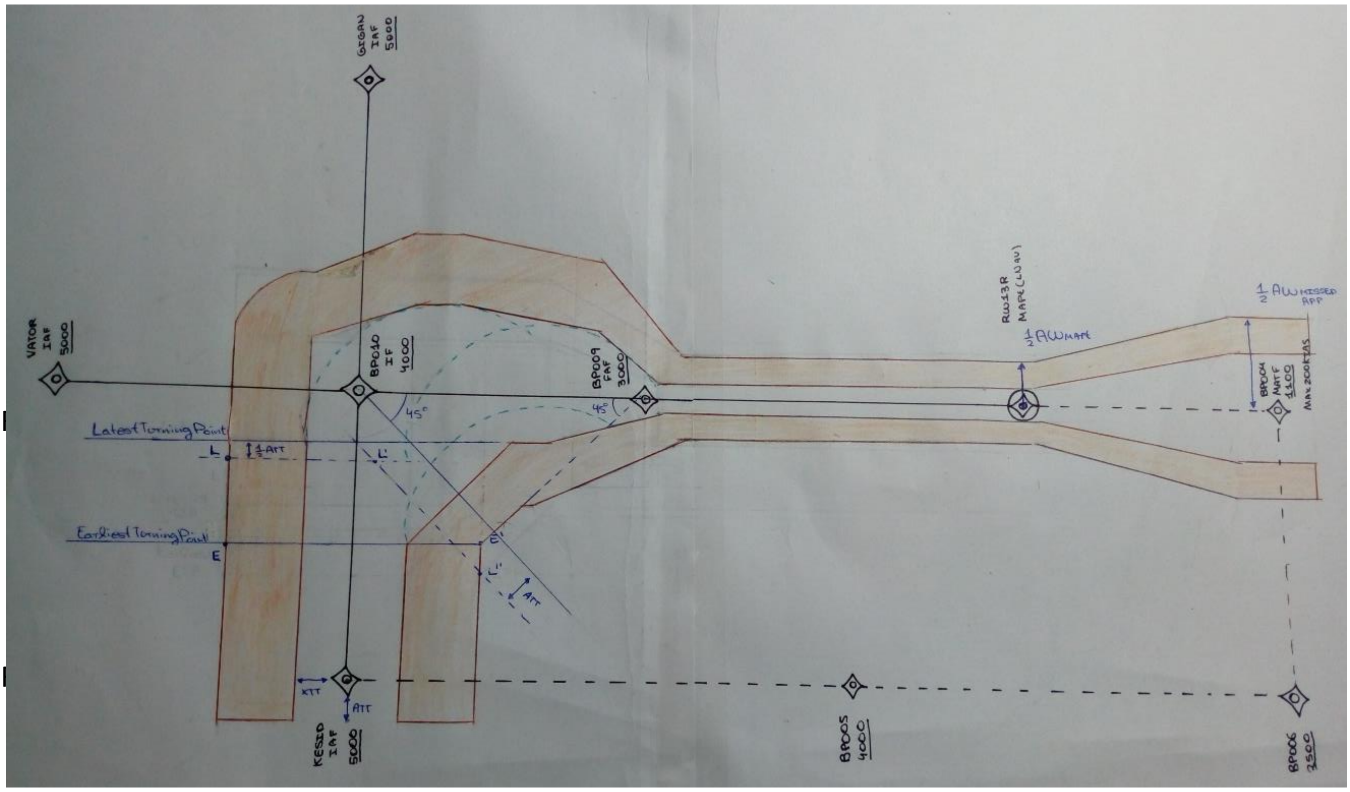
$$\boldsymbol{LTP} = Min\left[rTan\left(\frac{A}{2}\right), r\right] - ATT - (Vtas * Pilot\ Reaction\ Time)$$

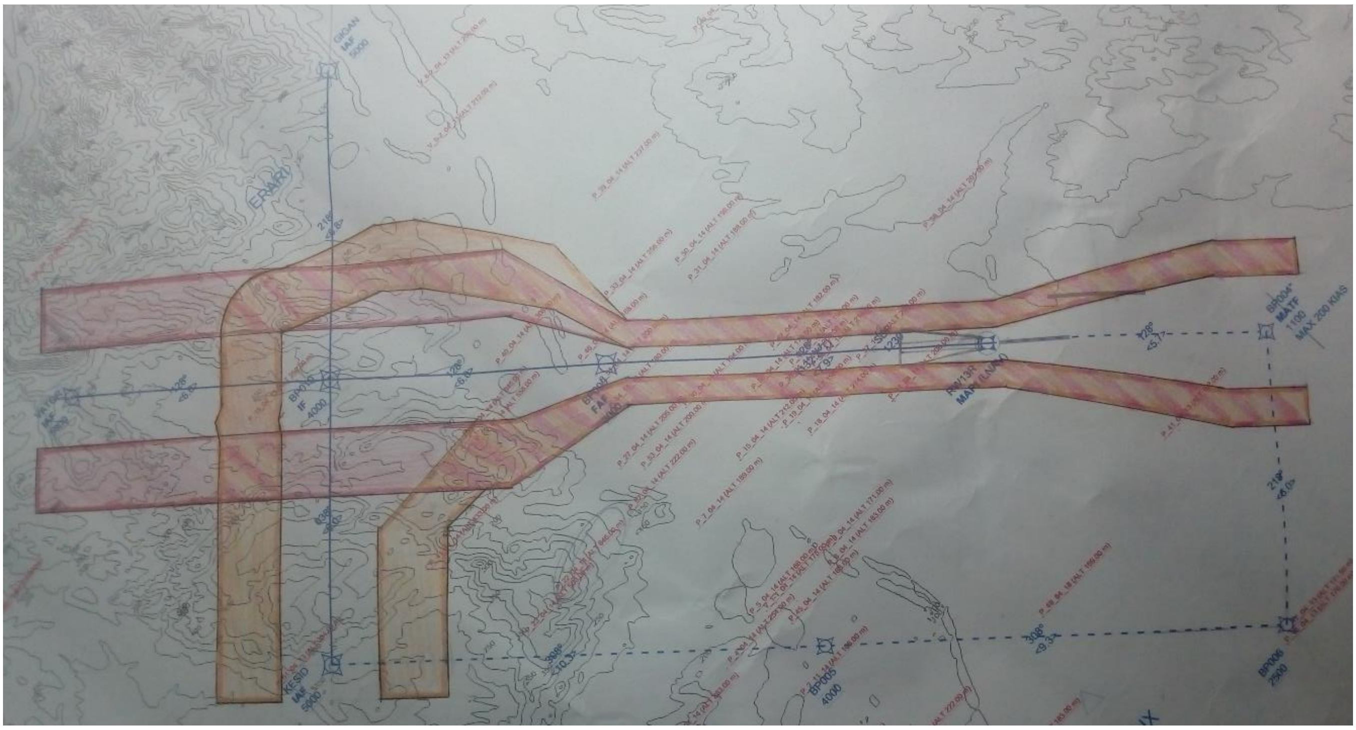
Where the Pilot Reaction Time is 6s, ATT is the along-track tolerance which is 0.8NM, the Vtas is 277kt and the A is 90º.

ETP=3.19NM

LTP=1.13NM

Now that we got all the data that we need we can follow the schematic to draw the protection areas for the turning procedures. We will only draw it for the IAF KESID since the IAF GIGAN is symmetric.





TERMINAL ARRIVAL ALTITUDE (TAA):

Terminal arrival altitudes (TAAs) should be established for any RNAV procedure based upon the T or Y arrangement . The TAA reference points are the initial approach and/or intermediate fixes (TAA is calculated for the initial segment).

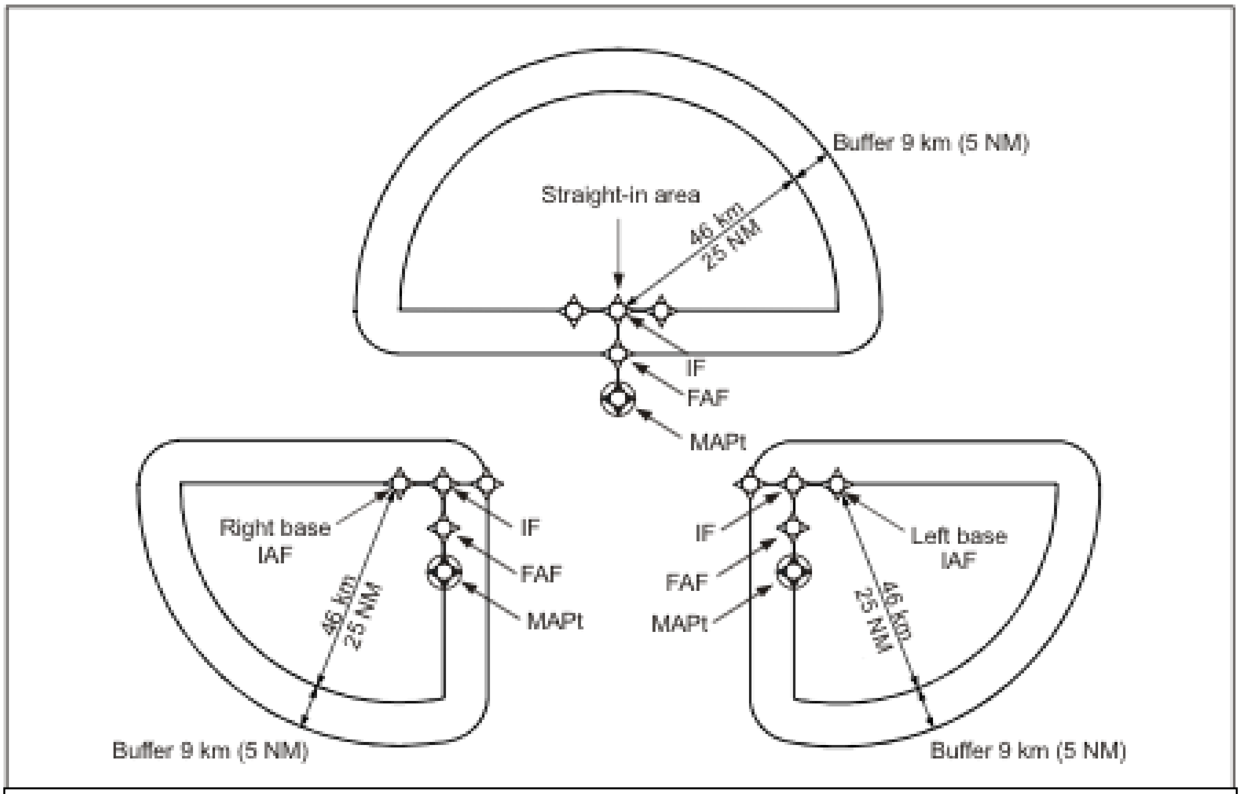


Figure 4.1 *(Source : [4])*

The formula to calculate TAA is given and it is :

TAA = MAX_OBST_ALT +1000 ft (300 m)

Each result has to be rounded to the next higher 100 ft increment, as appropriate.

Where the first term of the left part of the equation corresponds to the maximum altitude among all the ones of obstacles belonging to a specific area or sector in the chart, with circular geometry of 25 NM radius, centred on the RNAV waypoints on which the instrument approach is based.

In total, we have to draw three different areas to which will correspond three different TAAs and they are (see figure) :

- **Straight-in area** (center : IF)
- **Right base area** (center : right base IAF)
- **Left base area** (center : left base IAF)

In order to increase the safety of the approach procedure, another extra area, called Buffer area, is added to the three above. It is defined as a circular crown, concentric with the previous circles, of radius 5 NM.

- **<u>IAF VATOR</u> (Straight-in area)**

The maximum obstacle in this area that we have found is 757 m above the surface, so the TAA in this initial segment is:

TAA = 757 m + 300 m = 1057 m = 3467,84 ft = **3500 ft (rounded)**

- **<u>IAF KESID</u> (Right base area)**

The maximum obstacle in this area that we have found is 646 m above the surface, so the TAA in this initial segment is:

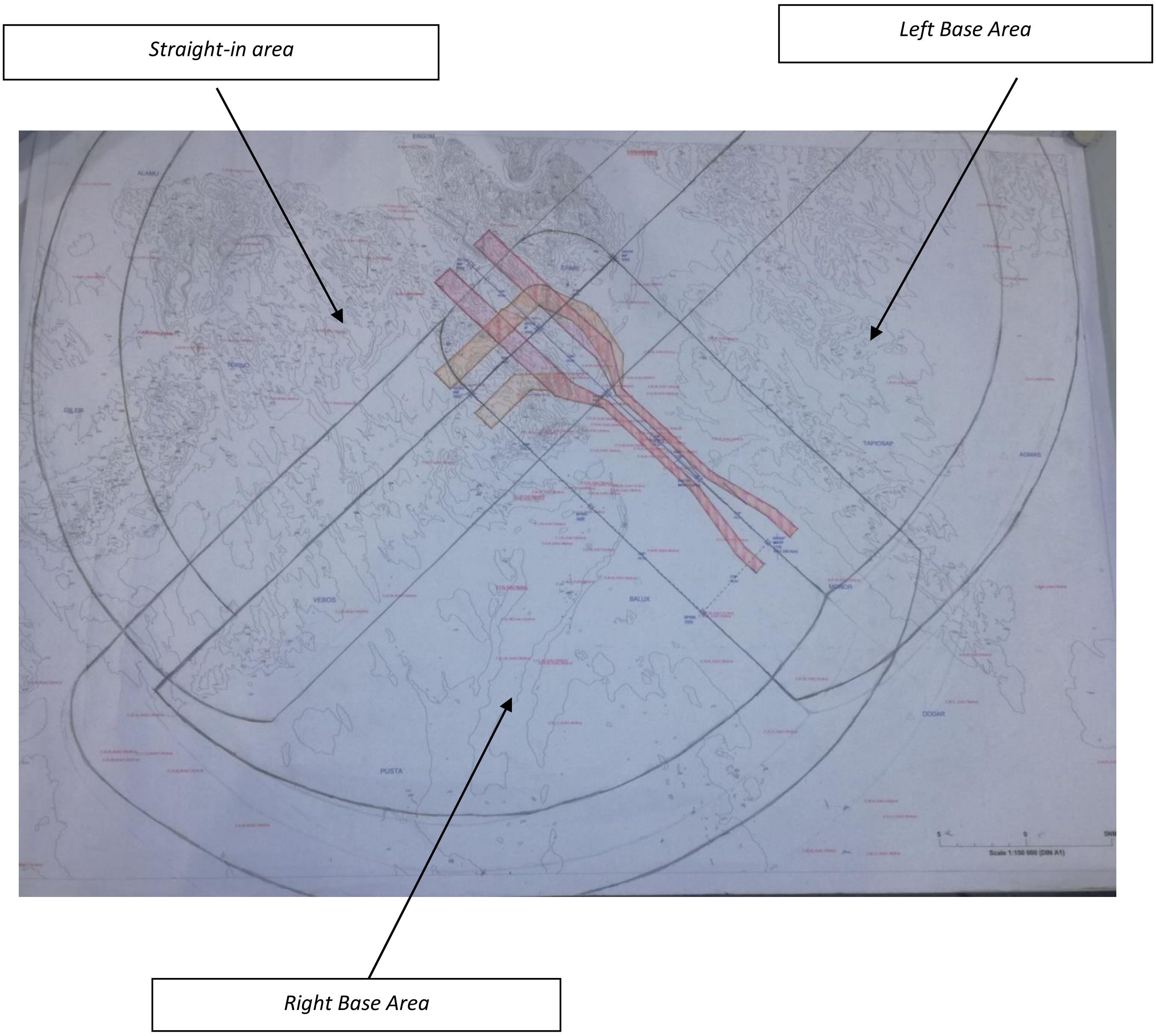
TAA = 646 m + 300 m = 946 m = 3103,67 ft = **3200 ft (rounded)**

- **<u>IAF GIGAN</u> (Left base area)**

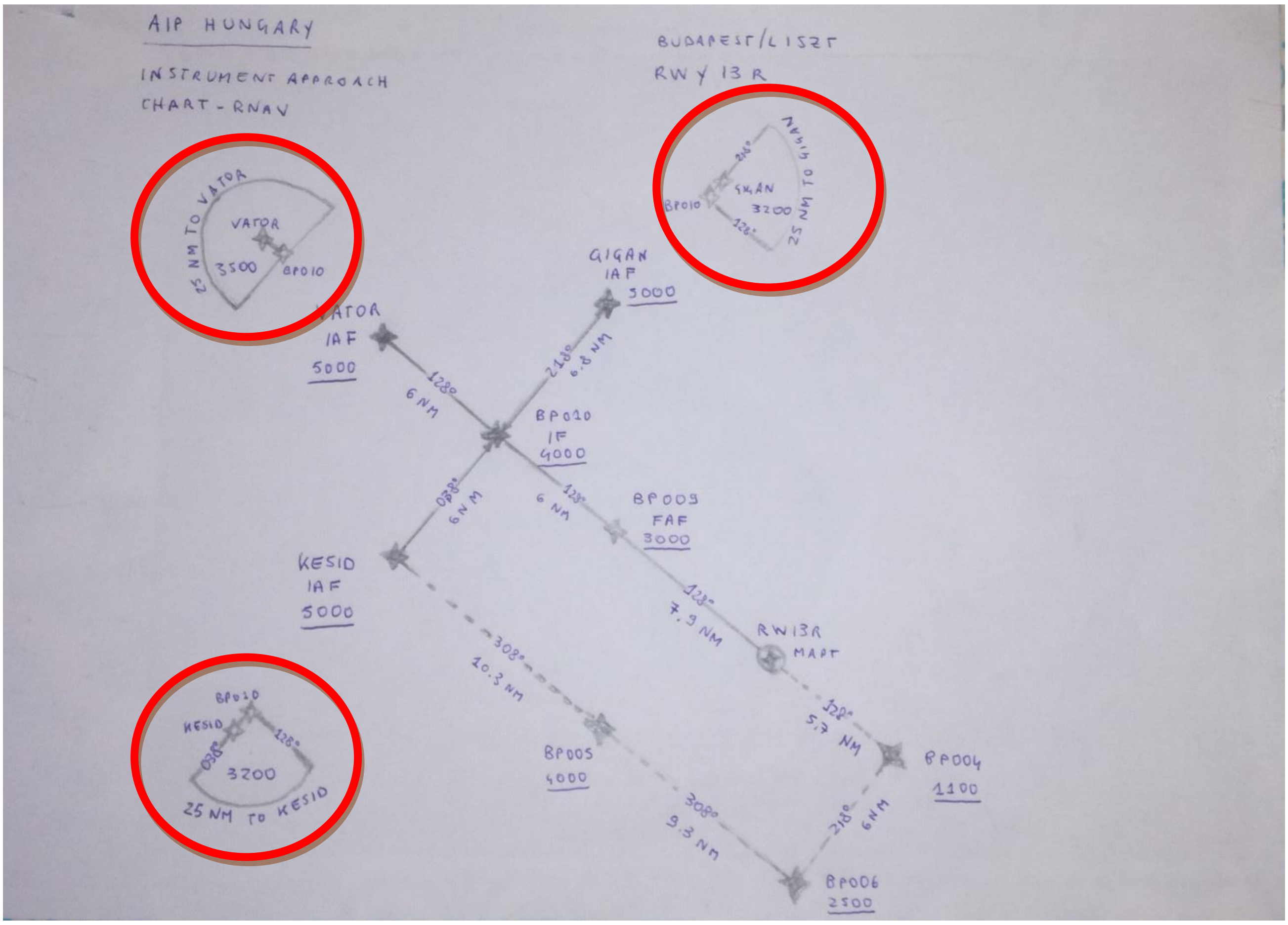
The maximum obstacle in this area that we have found is 285 m above the surface, so the TAA in this initial segment is:

TAA = 646 m + 300 m = 585 m = 3103,67 ft = **3200 ft (rounded)**

Once we have calculated all the TAAs in our procedure we have to draw them in our chart :



And doing a skecth in order to see it better :



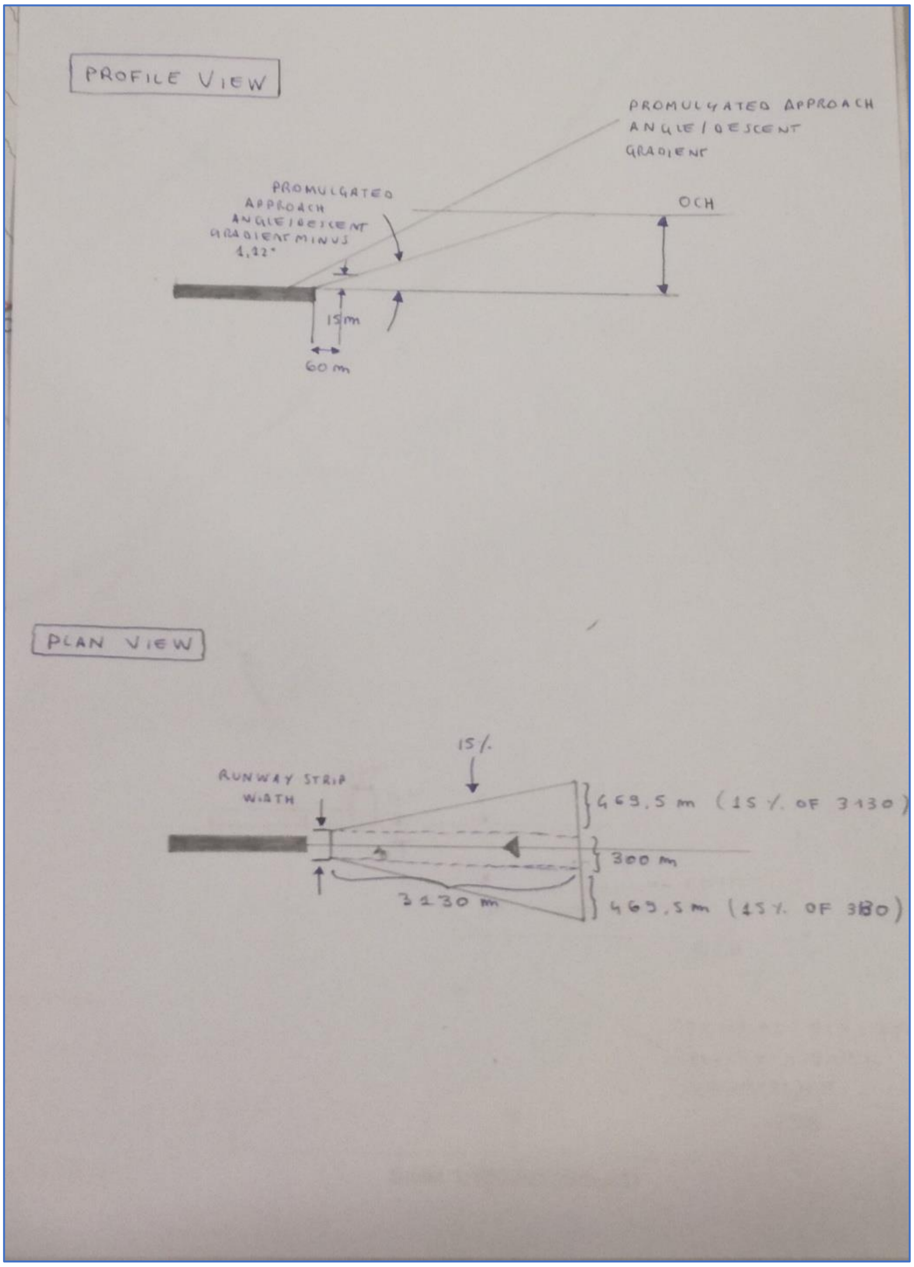
Comparing it with the official chart publicated in Atenea, we see that the TAA that we have calculated for KESID is the same of the one in the chart, but the other two TAAs for GIGAN and VATOR fix points are different. Actually, the TAAs that are in the official chart are 4200 ft for VATOR and 3800 for GIGAN. The reason of this difference of values is due to the fact that, as the chart we analyzed had smaller dimensions with respect to the official, we consequently took into consideration a smaller part of the chart to calculate TAAs, neglecting the altitudes that were in the designated area but that we couldn't see.

Visual Segment Surface (VSS):

All new straight-in instrument approach procedures published on or after 15 March 2007 shall be protected for obstacles in the visual segment. For this purpose a Visual Segment Surface is provided and no obstacles shall penetrate it.

It is defined according two different points of view :

1) **Profile view**
2) **Plan view**



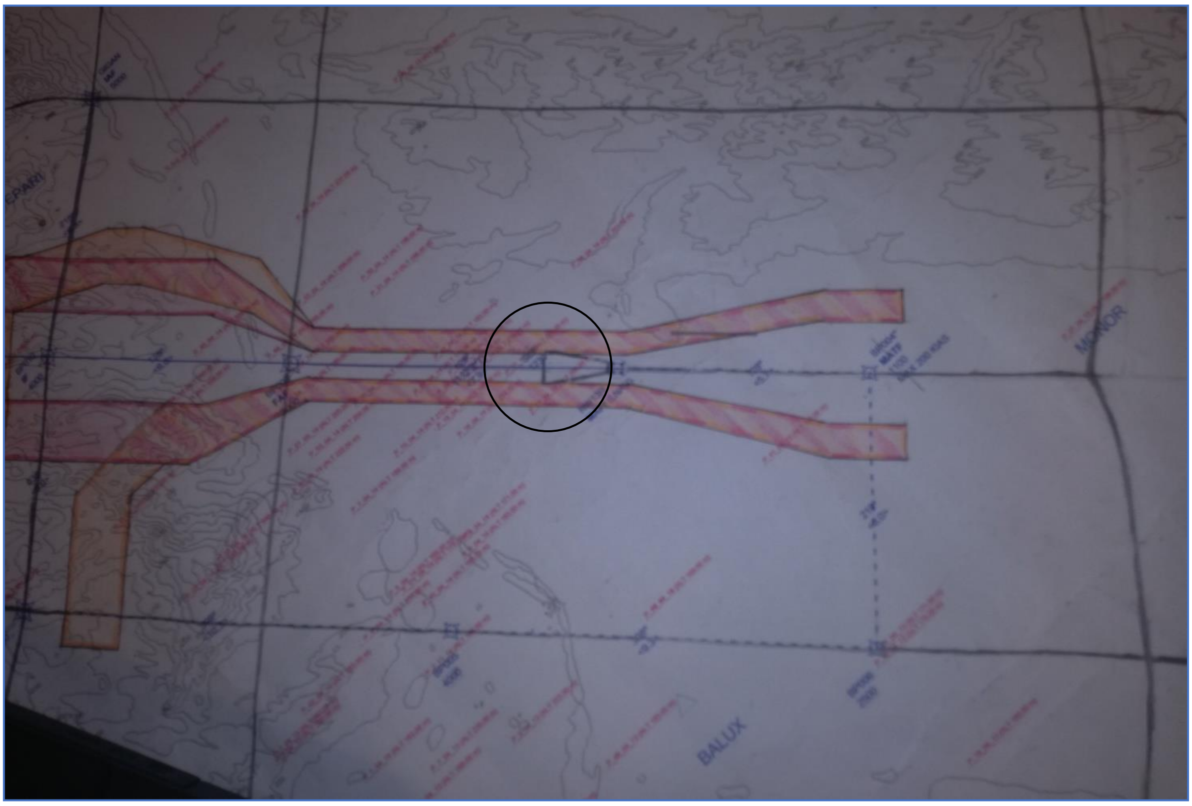
1) **Vertically**, the VSS originates 60 m prior the runway threshold and has a slope of 1.12 degrees less than the promulgated approach angle, terminating at the point where its height reaches the OCH. The promulgated approach angle is defined as h/d, where h is the vertical distance between the altitude/height over the FAF and the elevation 15 m (50 ft) that is 2250 ft in this case and d is the horizontal distance from the FAF to the threshold, in this case 7,9 NM.

2) According to the **plan view**, the VSS is represented by a rectangle that originates 60 m prior the runway threshold defined by strip dimensions (from **Table A**) that is splayed 15 per cent on either side of the extended runway centre line and terminating as before at the point corresponding to the OCH.

Designation Runway	Strip Dimensions (m)
13 R	3130 x 300
31 L	3130 x 300
13 L	3827 x 300
31 R	3827 x 300

(Table A – Source : [6])

Drawing it in the chart, it results :



Conclusions:

In this project we were able to learn about how the design of procedures is done. Since this is a very standarised and reguled science we only had to follow the ICAO regualtions document we were provided, Procedures for Air Navigation Services (PANS-OPS).

To learn about the designing process of a procedure we had to redesign an existent chart and check that each of its features meet the regulations set by ICAO.

As we went through the PANS-OPS guide we found that some aspects of our redesigning process did not match the actual chart but of course we do not conclude that the real chart is not properly designed.

We reckon that the inconsistencies between our design and the real chart are due to our reduced cartographic area of study or assumptions that we did differently to procedure designers such as the angle of turn.

Our conclusions are that the design of procedures requires considering many parameters with a high level of precision and ensure safety above everything else to meet the regulations and be implemented in reality.

Bibliography:

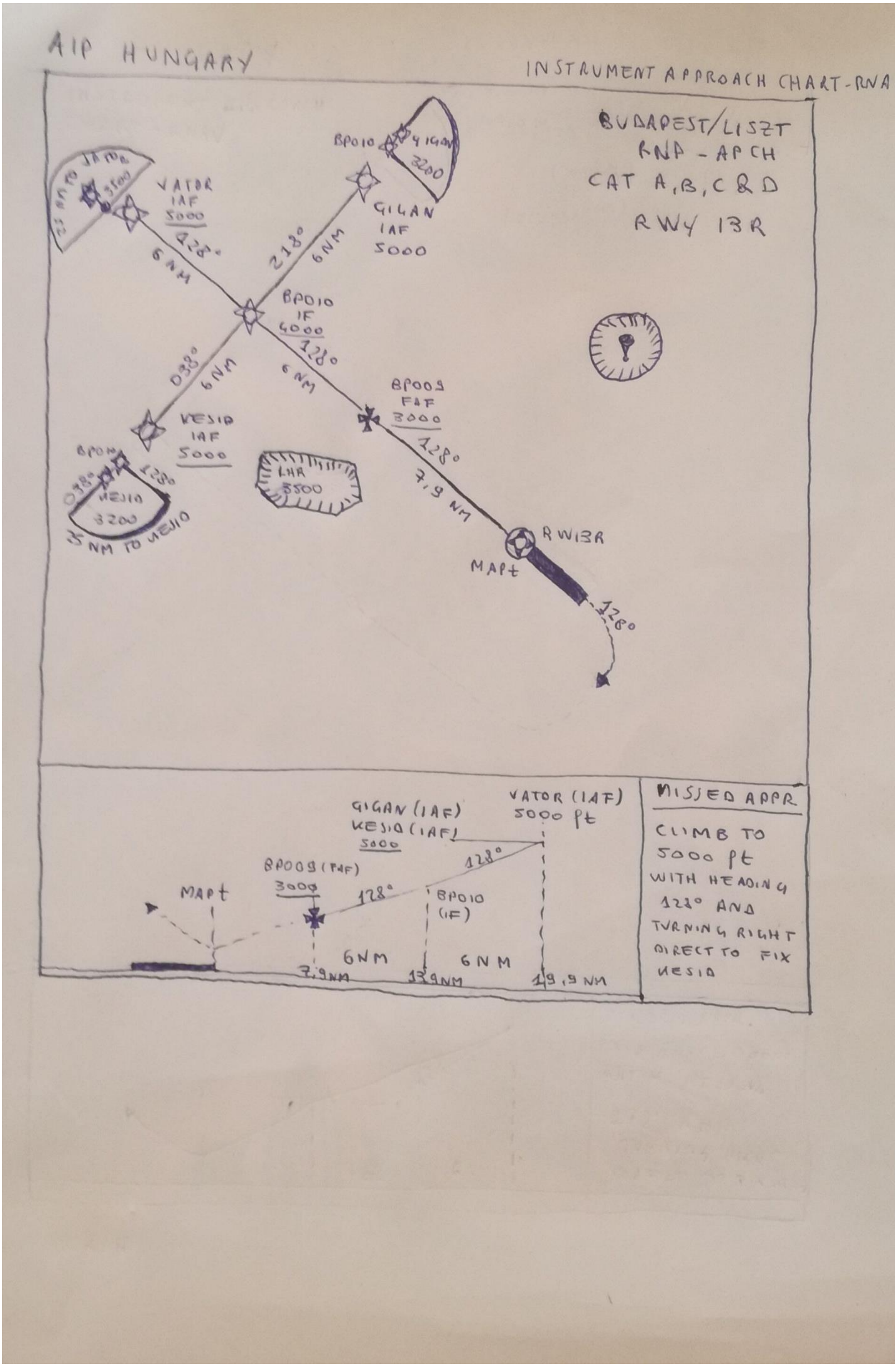
[1] : ICAO-Doc8168_Vol2_6ed_2014 : Part III- Section 2- Chapter 1

[2] : ICAO-Doc8168_Vol2_6ed_2014 : Part I – Section 4 – Chapter 5

[3] : ICAO-Doc8168_Vol2_6ed_2014 : Part III – Section 3 – Chapter 2

[4] : ICAO-Doc8168_Vol2_6ed_2014 : Part III – Section 2 – Chapter 4

[5] : ICAO-Doc8168_Vol2_6ed_2014 : Part I – Section 4 – Chapter 5


AIP HUNGARY
INSTRUMENT APPROACH CHART-RNAV
BUDAPEST/LISZT
RNP - APCH
CAT A,B,C & D
RWY 13R
VATOR
IAF
5000
GIGAN
IAF
5000
BP010
IF
4000
BP009
FAF
3000
KESID
IAF
5000
128°
218°
038°
6NM
7,9 NM
LHR
3500
3200
RW13R
MAPt
25 NM TO KESID
GIGAN (IAF)
KESID (IAF)
5000
VATOR (IAF)
5000 ft
BP009 (FAF)
3000
BP010
(IF)
MAPt
7,9NM
13,9NM
19,9 NM
MISSED APPR.
CLIMB TO
5000 ft
WITH HEADING
128° AND
TURNING RIGHT
DIRECT TO FIX
KESID