TNyCA

Grado Aeroespacial

Flight planning

Joan Vila Carbó

Bibliography

- **Descubrir la navegación aérea**
  - F.J. Sáez Nieto, Y. Portillo Pérez.
    - *Publicado por Aena*

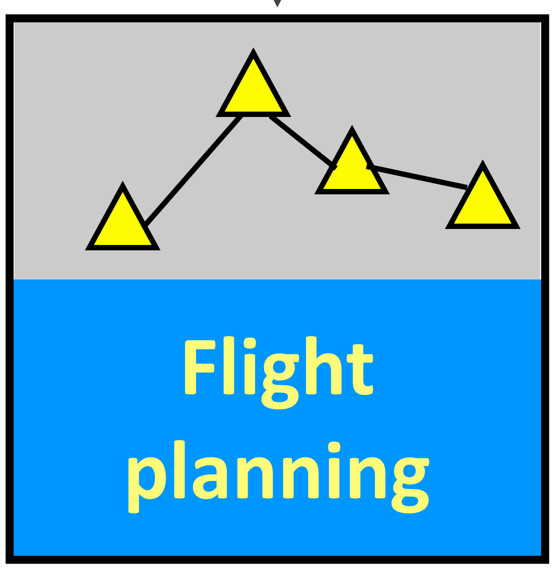
Flight planning

- **Introduction**
- **Flight phases**
- **Planning a Madrid-Barcelona flight**
  - En-route
  - SID - Standard Instrument Departure
  - STAR - Standard Arrival
  - IAC - Instrument Approach
- **The wind triangle**
- **The vertical profile**

Flight planning

Flight planning concept

ORG, DST



AIP
Operation manual
Weather forecast

For ATS

ICAO flight plan
Route
Flight type
Departure time
Equipment on board
Fuel consumption estimation

For pilot

Route description
Navigation charts
Waypoints
Speeds
Timing
Fuel consumption
Weather forecast

ICAO flight plan

Doc 4444 - PANS ATM

LIDO flight plan

Available for example at
http://www.simbrief.com/system/register.php?

Flight planning

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Flight planning concept

- Process of producing two sets of documents:
  - *An **ATC flight plan** which provides specified information to ATS (Air Traffic Service) units relative to an intended flight so they can **minimize the risk of midair collision** and provide orderly flow of traffic. It can also trigger the **Alert Service** if the flight does not reach the waypoints at the estimated times and communication with the aircraft is lost.*
    - It is a **standard form** defined by ICAO Annex 2: Rules of the Air.
    - It must comply with ATC requirements and must be **approved before flight.**
  - *A **route description for the pilot** containing the required navigation charts, all the flight waypoints and flight procedures. The goal is to help the pilot in the **guidance process**. It includes a **timing** calculation and a **fuel consumption** estimation to ensure that the aircraft can safely reach the destination. It requires accurate weather forecasts.*
    - Non **standard.** It is an extended **ATC flight plan.** Example: Lido flight plan.

Flight planning

ATC flight plan

- Statement of intentions that basically provides the ATCO with the route and the de departure time so he can compute can compute estimated times for each waypoint. It is a report with all important data for a flight:
  - ***Route***: *place of departure, destination, alternate destination, altitude, cruising speed, estimated time en route and waypoints, …*
  - ***Departure time***: *Estimated off-block time. Approval requires complying with the time slots.*
  - ***Technical information***: *registration of the aircraft, navigation equipment, transponder type, rescue equipment found in the aircraft.*
  - ***Flight type***: *General Aviation, Military, Scheduled flight, Non-Scheduled flight.*
  - ***Wake Turbulence Category***: *Light, Medium, Heavy.*
  - ***Fuel computation*** *and reserves.*
  - *Other ...*

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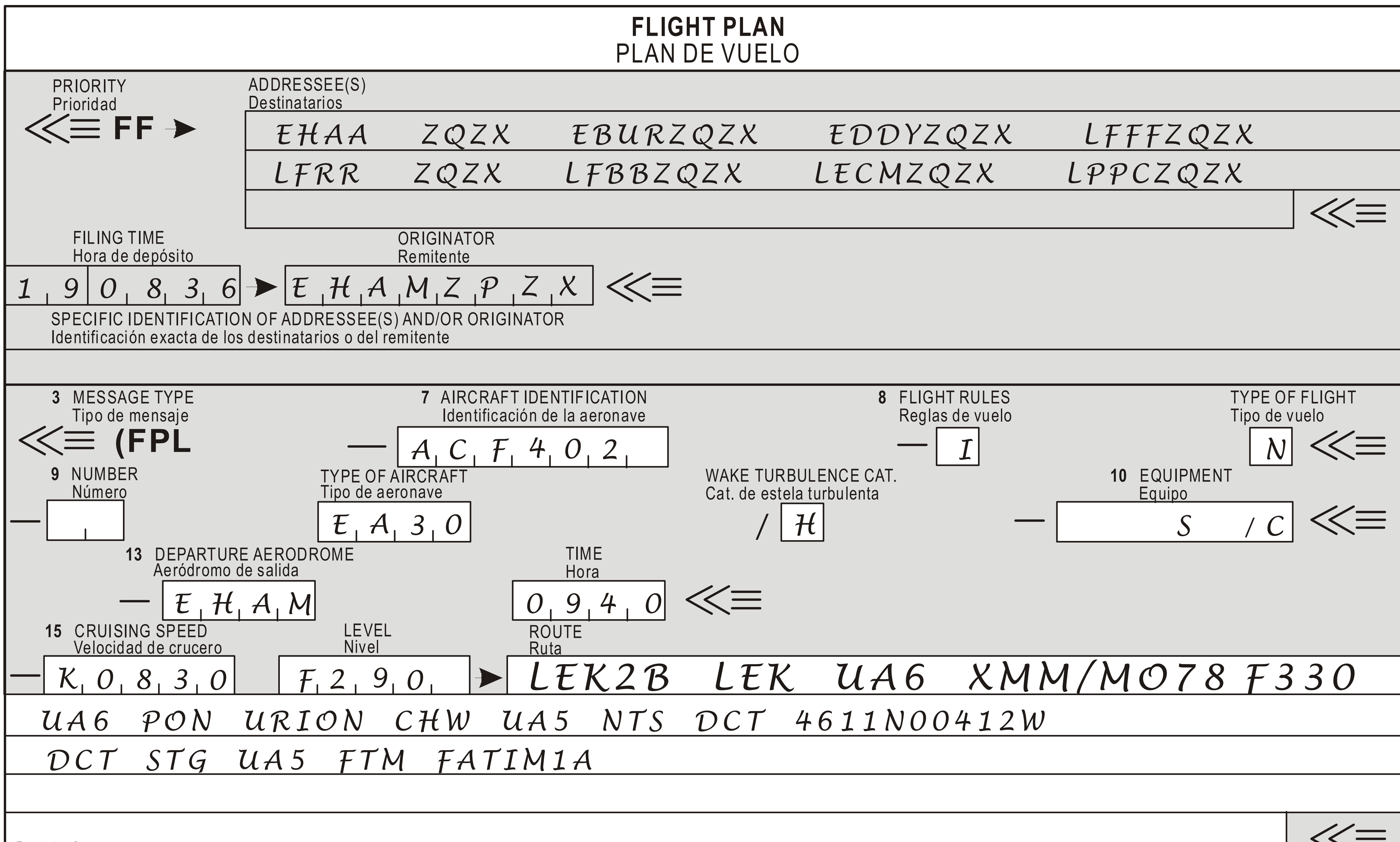
Flight planning

ICAO flight plan

- ICAO Doc 4444 - PANS ATM



FLIGHT PLAN
PLAN DE VUELO

PRIORITY / Prioridad: ≪≡ FF ➤

ADDRESSEE(S) / Destinatarios:
EHAA ZQZX EBURZQZX EDDYZQZX LFFFZQZX
LFRR ZQZX LFBBZQZX LECMZQZX LPPCZQZX ≪≡

FILING TIME / Hora de depósito: 190836 ➤

ORIGINATOR / Remitente: EHAMZPZX ≪≡

SPECIFIC IDENTIFICATION OF ADDRESSEE(S) AND/OR ORIGINATOR
Identificación exacta de los destinatarios o del remitente

3 MESSAGE TYPE / Tipo de mensaje: ≪≡ (FPL

7 AIRCRAFT IDENTIFICATION / Identificación de la aeronave: — ACF402

8 FLIGHT RULES / Reglas de vuelo: — I

TYPE OF FLIGHT / Tipo de vuelo: N ≪≡

9 NUMBER / Número: —

TYPE OF AIRCRAFT / Tipo de aeronave: EA30

WAKE TURBULENCE CAT. / Cat. de estela turbulenta: / H

10 EQUIPMENT / Equipo: — S / C ≪≡

13 DEPARTURE AERODROME / Aeródromo de salida: — EHAM

TIME / Hora: 0940 ≪≡

15 CRUISING SPEED / Velocidad de crucero: — K0830

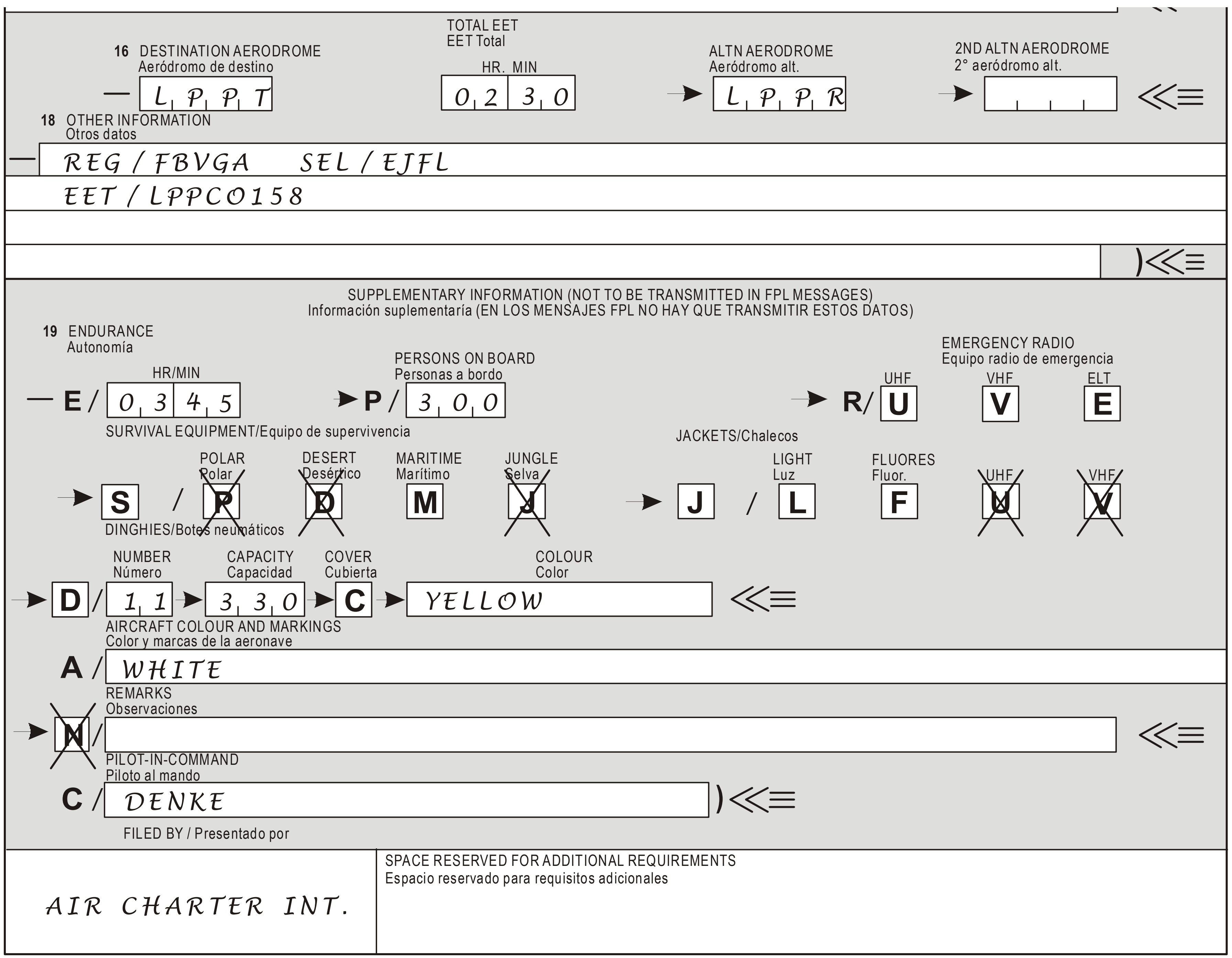
LEVEL / Nivel: F290 ➤

ROUTE / Ruta:
LEK2B LEK UA6 XMM/M078 F330
UA6 PON URION CHW UA5 NTS DCT 4611N00412W
DCT STG UA5 FTM FATIM1A

≪≡

Flight planning

- **ICAO flight plan**
  - ICAO Doc 4444 - PANS ATM


16 DESTINATION AERODROME
Aeródromo de destino
TOTAL EET
EET Total
HR. MIN
— LPPT 0230
ALTN AERODROME
Aeródromo alt.
→ LPPR
2ND ALTN AERODROME
2° aeródromo alt.
18 OTHER INFORMATION
Otros datos
— REG / FBVGA SEL / EJFL
EET / LPPC0158
)

SUPPLEMENTARY INFORMATION (NOT TO BE TRANSMITTED IN FPL MESSAGES)
Información suplementaria (EN LOS MENSAJES FPL NO HAY QUE TRANSMITIR ESTOS DATOS)

19 ENDURANCE
Autonomía
HR/MIN
— E / 0345
PERSONS ON BOARD
Personas a bordo
→ P / 300
EMERGENCY RADIO
Equipo radio de emergencia
UHF VHF ELT
→ R / U V E
SURVIVAL EQUIPMENT/Equipo de supervivencia
POLAR Polar, DESERT Desértico, MARITIME Marítimo, JUNGLE Selva
→ S / ~~P~~ ~~D~~ M ~~J~~
JACKETS/Chalecos
LIGHT Luz, FLUORES Fluor., UHF, VHF
→ J / L F ~~U~~ ~~V~~
DINGHIES/Botes neumáticos
NUMBER Número, CAPACITY Capacidad, COVER Cubierta, COLOUR Color
→ D / 11 → 330 → C → YELLOW
AIRCRAFT COLOUR AND MARKINGS
Color y marcas de la aeronave
A / WHITE
REMARKS
Observaciones
→ ~~N~~ /
PILOT-IN-COMMAND
Piloto al mando
C / DENKE)
FILED BY / Presentado por
AIR CHARTER INT.
SPACE RESERVED FOR ADDITIONAL REQUIREMENTS
Espacio reservado para requisitos adicionales

Flight planning

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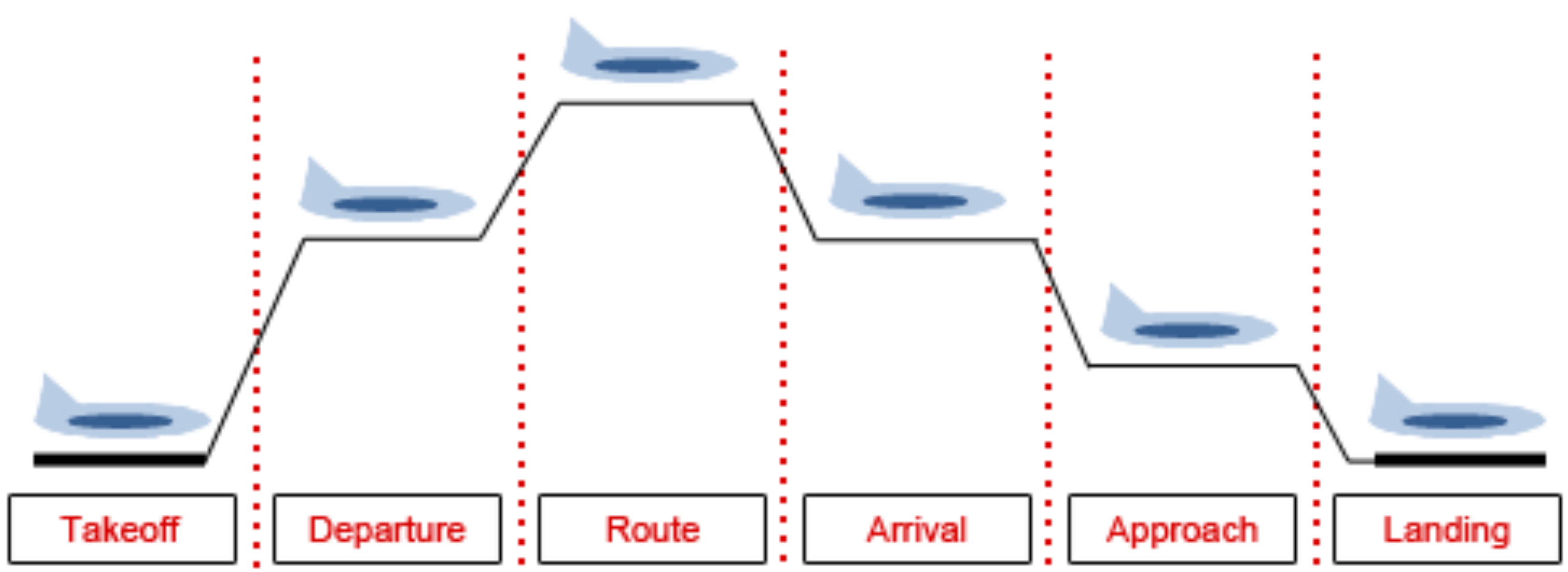
Flight phases

Flight phase taxonomy

The **phases of flight** are the different periods of time or operational phases in which a flight is structured:

- Preflight, Taxi and Take off
- Departure
- En route / cruising
- Arrival
  - *Holding / Loiter*
- Approach
  - *Initial*
  - *Intermediate*
  - *Final*
  - *Missed Approach*
- Landing



Flight phases

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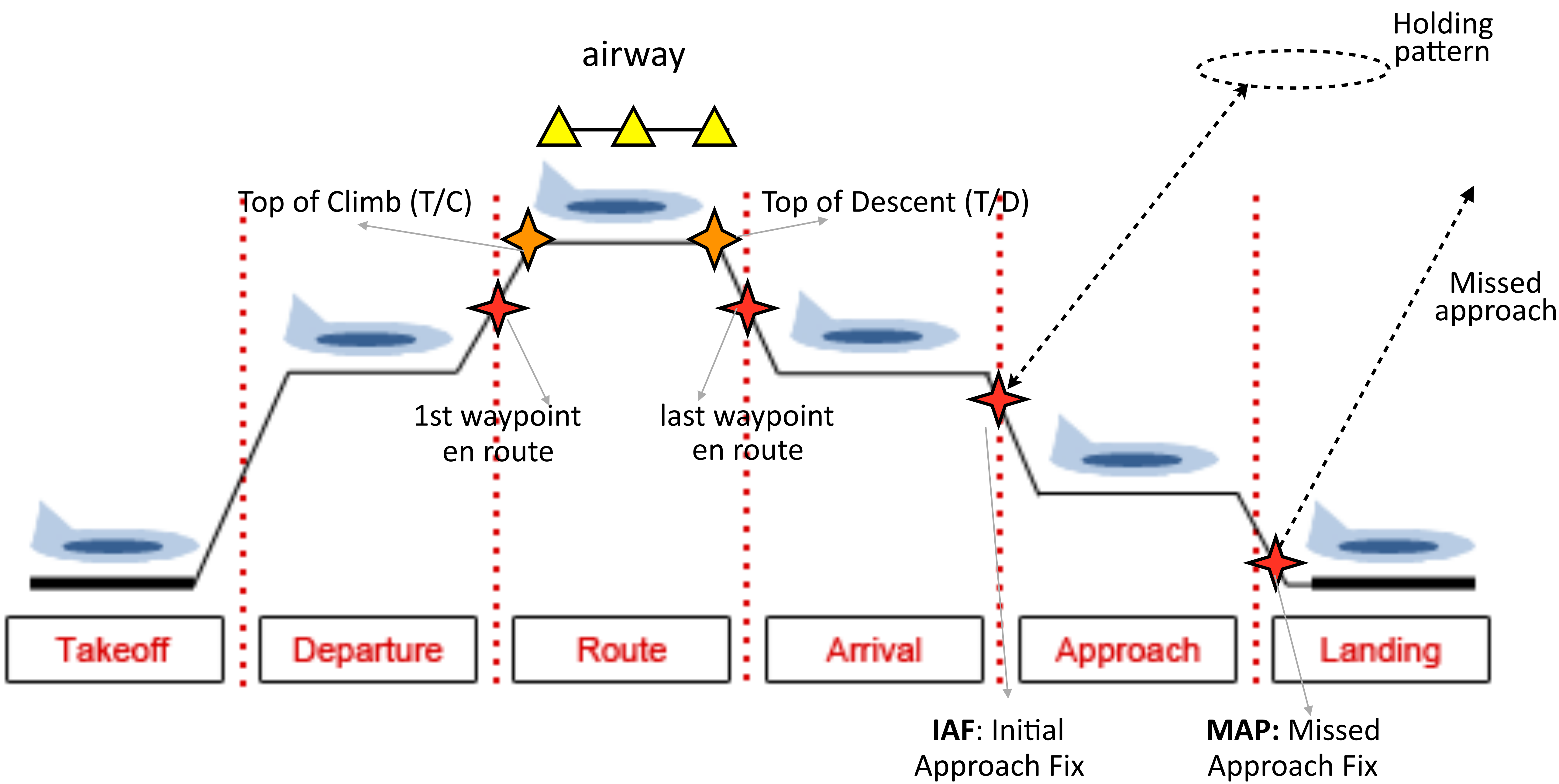
- **Important fixes**



Flight phases

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- **Taxi**
  - The aircraft is moving on the aerodrome surface under its own power prior to takeoff or after landing.
  - **Subphases**: *Engines Not Operating*, *Engines Start-up*, *Engines Operating*, *Engines Shut Down*, *Pushback /Towing* assisted by a tow vehicle (tug).
- **Take-off**
  - From the application of take-off power, through rotation and to an altitude of 35 feet above runway elevation.
  - It may finish in a *Rejected Takeoff* if the decision to abort has been taken.

Flight phases

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- **Departure**
  - The aircraft continues to climb by a departure route (SID) until reaching the a proper height for the cruise.
  - **Subphases**: one/several climb section and one/several acceleration sections.
    - ***Initial climb***: *from the end of the Takeoff subphase to the first prescribed power reduction, or until reaching 1,000 feet above runway elevation or the VFR pattern, whichever comes first. Flaps sometimes extended.*
    - ***Climb to Cruise***: *from completion of Initial Climb to arrival at initial assigned cruise altitude. Flaps usually retracted.*

Flight phases

En route / cruising

- It is reached when the airplane reaches the proper altitude for flying most of the route.
  - *Conventional cruise routes are flown through **airways** comprise a set of **legs** (straight segments) that connect a set of significant waypoints or **fixes**.*
- **Airways** are defined in navigation charts. There are two types according to their altitude:
  - ***Upper Airspace** (above FL245): mainly used for cruise phase*
  - ***Lower airspace** (below FL245): some cruise routes and approaches.*
- **Significant waypoints/fixes**: they include airfields, navaids, reporting points (mandatory or optional), or GPS defined points. They can be:
  - *Beaconed using a navaid*
  - *Not beaconed.*

Flight phases

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- **Arrival**
  - Set of maneuvers that take the aircraft from the last en route waypoint of the flight plan to a waypoint called **IAF** (*Initial Approach Fix)*.
    - ***IAF*** *(Initial Approach Fix): starting point of an approach where, if the flight might conflict with other aircrafts, it waits in a* ***holding pattern*** *until it is authorized to proceed.*
  - **Subphases**: several descents from cruise level (30.000 ft) until reaching the altitude for the approach (7000 ft) and final approach (3000 ft).
  - **Holding pattern**: Execution of a predetermined maneuver, usually oval racetrack pattern, flown by aircraft awaiting clearance to land at an airport.

Flight phases

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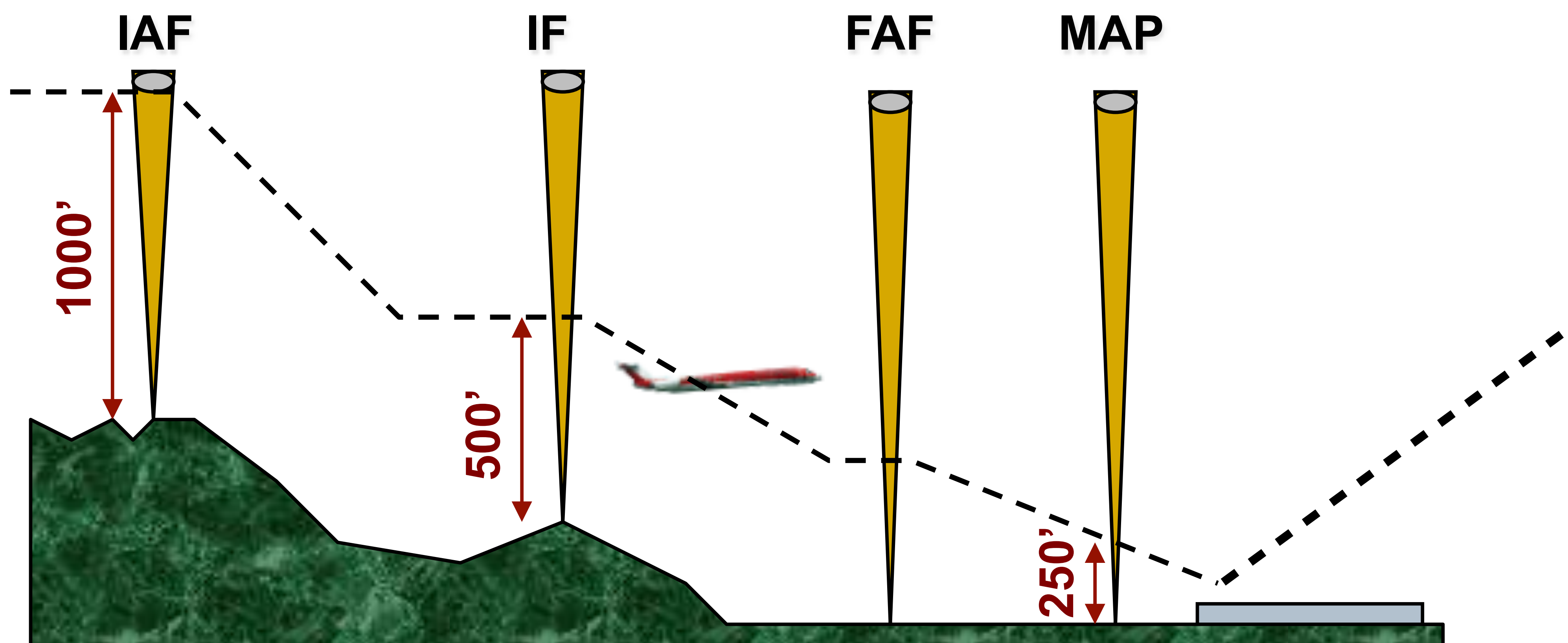
Approach

- Set of predetermined maneuvers that allow an aircraft to safely evolve separated from land obstacles, from the **IAF** (or 1,000 feet above the runway) to the beginning of the landing flare.
- Its takes the aircraft to a point called **D/H** (*Decision Height*) in which:
  - *If there exists visual references to the runway, the descent continues until landing.*
  - *If there is no visual contact, the descent manouvre is aborted and the* ***missed approach*** *is undertaken.*
- **Missed approach:** intersection of the glideslope (descent at a ROD rate of descent of 3o or 5.2%) and the Decision Height (DH)
  - *It comprises from the first application of power after the crew elects to execute a missed approach or go-around until the aircraft re-enters the sequence for a VFR pattern (go-around) or until the aircraft reaches the IAF for another approach (IFR).*

Flight phases

Approach subphases



Initial Approach	Intermediate Approach	Final Approach	Landing/ Missed Approach
Align with runway course	Change aircraft configuration: speed adjust and flaps 50%	Follow glideslope	

- **IAF** - *Initial Approach Fix*
- **IF** - *Intermediate Approach Fix*
- **FAF** - *Final Approach Fix*
- **MAP** - *Missed Approach Point*

Flight phases

Importance of flight phases

- Each phase has its own associated characteristics:
  - *It evolves through different **airspaces**.*
  - *It has its own specific **navigation charts**.*
  - *It has its own **operational procedures**.*
  - *It has its own **air traffic control** problems which are solved by different control units.*
    - **TOW** (Tower), **APP** (Approach), **ACC** (Area Control Center)
  - *It uses different **navigation aids.***
    - **GNSS, VOR, DME, ILS**
  - *Required **navigation accuracy** is different for each phase.*
    - Autopilots have different operating modes depending on the phase of flight and the accuracy
  - ***Accidents statistics** also depend heavily on the flight phase*

Flight phases

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Flight phases and RNP (Required Navigation Performance)

Navigation Specification	Flight Phase							
	En Route Oceanic Remote	En Route Continental	ARR	Approach				DEP
				Initial	Intermed	Final	Missed	
RNAV 10 (RNP 10)	10							
RNAV 5		5	5					
RNAV 2		2	2					2
RNAV 1		1	1	1	1		1	1
RNP4	4							
RNP2	2	2						
RNP1			1	1	1		1	1
Advanced RNP	2	2 or 1	1	1	1	0.3	1	1
RNP APCH				1	1	0.3	1	
RNP AR APCH				1-0.1	1-0.1	0.3-0.1	1-0.1	
RNP 0.3		0.3	0.3	0.3	0.3	-	0.3	0.3

Flight phases

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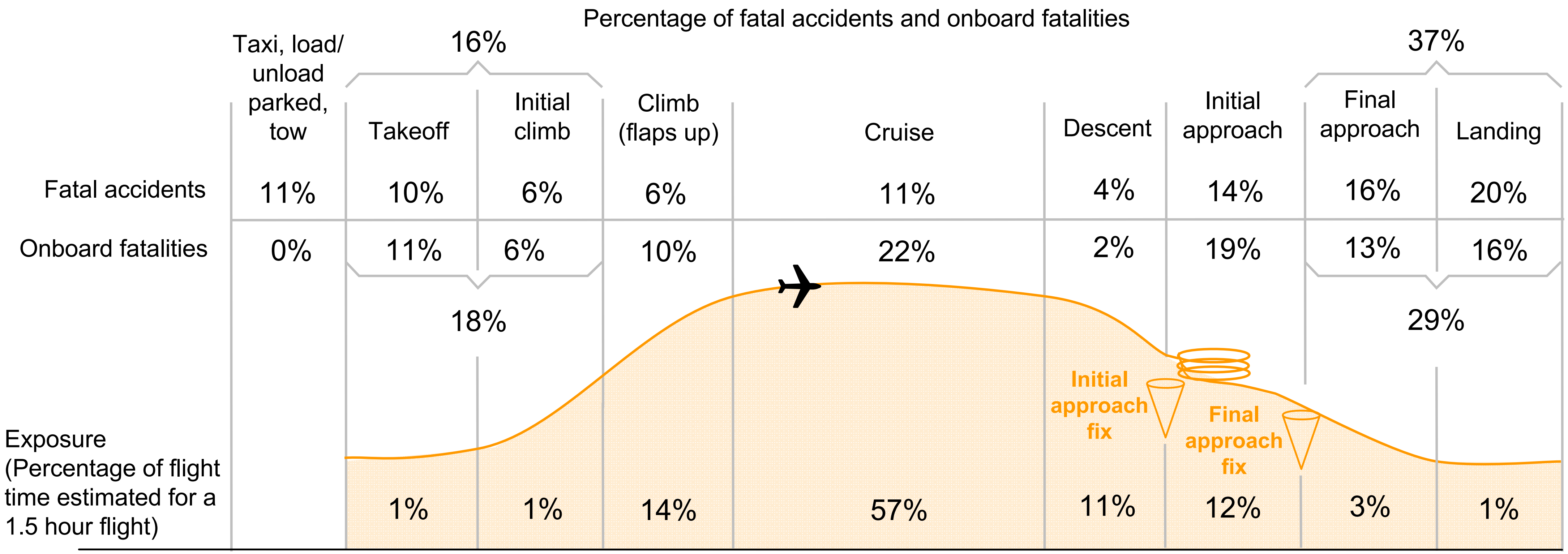
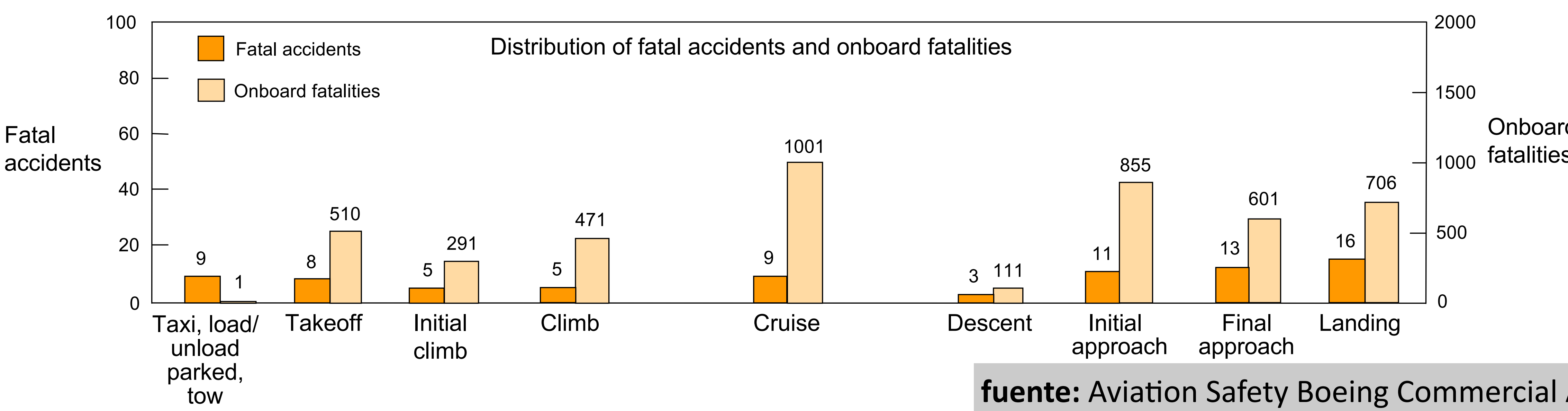
Flight phases and Fatal Accidents and Onboard Fatalities

Worldwide Commercial Jet Fleet – 2002 Through 2011



Percentages may not sum precisely due to numerical rounding.



fuente: Aviation Safety Boeing Commercial Airplanes
http://www.boeing.com/news/techissues/pdf/statsum.pdf

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AIP - Aeronautical Information Publication

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- **AIP - (*Aeronautical Information Publication*)**
  - Defined by ICAO as a publication issued by or with the authority of a state containing aeronautical information of a lasting character essential to air navigation.
  - It is designed to be a manual containing thorough details of regulations, procedures and other information pertinent to flying aircraft in the particular country to which it relates.
  - It is usually issued by or on behalf of the respective civil aviation administration.
    - *ENAIRE AIP: https://ais.enaire.es/aip/*

- **Using the AIP to plan a Madrid-Barcelona flight**
  - **From**: LEMD RWY 36R
  - **To**: LEBL RWY 25R


Madrid airport
Photo Copyright © Pedro Peña
AIRLINERS.NET

- Barcelona airport

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Planning a Madrid-Barcelona flight

En-route phase

RouteFinder

*Route generator for PC flight simulation use - **NOT FOR REAL WORLD NAVIGATION***

(C)2005-2007 ASA srl - Italy

NAT: Eastbound track message identification is 277
NAT: Westbound track message identification is 277
NATs: NATE: can't identify fix 5630 (-1)
NATs: NATV: can't identify fix 4630 (-1)
Computed route from **ADOLFO SUAREZ MADRID/BARAJAS** (LEMD, LE) to **BARCELONA/EL PRAT** (LEBL, LE): 9 fixes, 267.6 nautical miles

```
Cruise altitude between FL330 and FL330
LEMD (0.0nm) -SID-> PINAR (53.3nm) -UN870-> SEGRE (63.7nm) -UN870->
BRITO (77.7nm) -UN870-> PISUS (106.7nm) -UN870-> GOVIG (119.8nm) -UN870->
PONEN (148.7nm) -UT600-> CASPE (182.8nm) -STAR-> LEBL (267.6nm)
```

Details:

ID	FREQ	TRK	DIST	Coords	Name/Remarks
LEMD		0	0	N40°28'20.00" W003°33'39.00"	ADOLFO SUAREZ MADRID/BARAJAS
PINAR		55	53	N40°58'49.10" W002°35'57.00"	PINAR
SEGRE		76	10	N41°01'22.20" W002°22'35.30"	SEGRE
BRITO		76	14	N41°04'44.70" W002°04'40.90"	BRITO
PISUS		76	29	N41°11'37.20" W001°27'18.00"	PISUS
GOVIG		76	13	N41°14'40.60" W001°10'16.90"	GOVIG
PONEN		76	29	N41°21'14.00" W000°32'51.40"	PONEN
CASPE		98	34	N41°16'06.40" E000°11'57.80"	CASPE
LEBL		88	85	N41°17'49.00" E002°04'42.00"	BARCELONA/EL PRAT

1st waypoint en route

last waypoint en route

Tracks are magnetic, distances are in nautical miles.

```
LEMD SID PINAR UN870 PONEN UT600 CASPE STAR LEBL
```

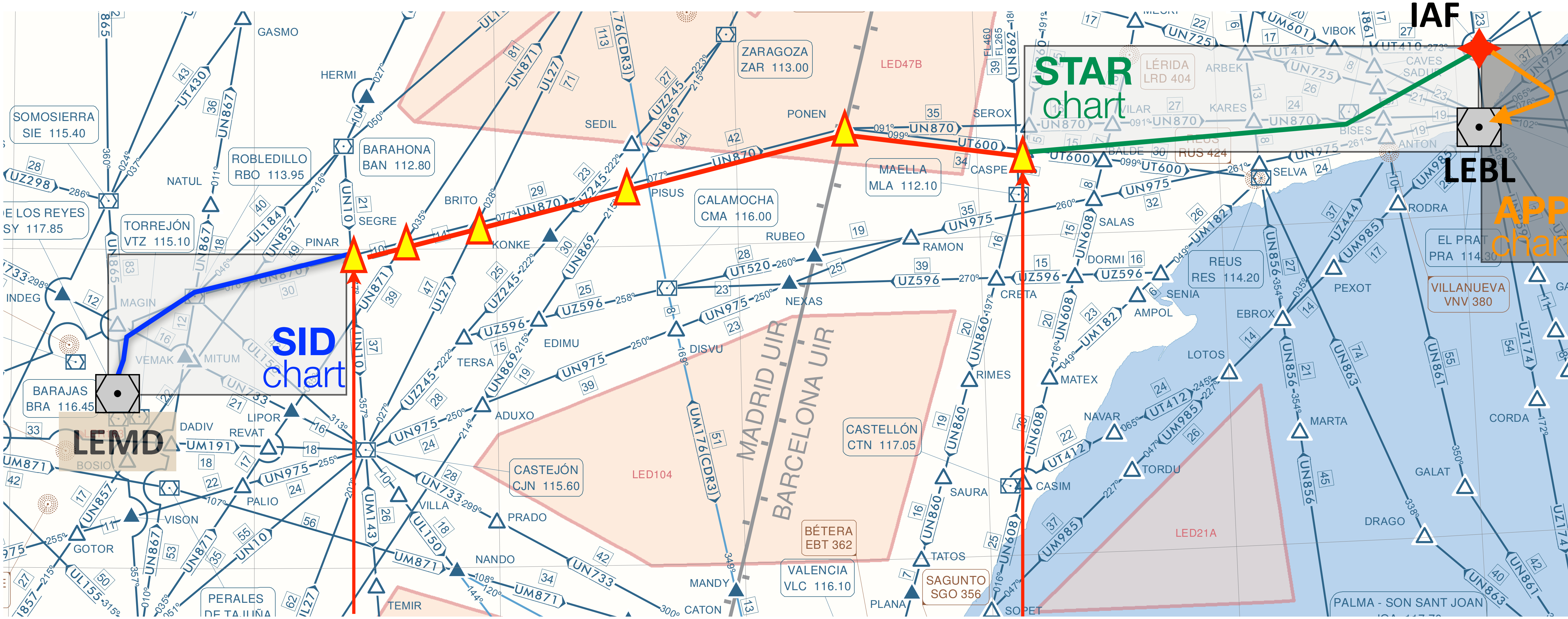
Planning a Madrid-Barcelona flight

- **En-route phase.**
  - **Upper airspace** / Lower Airspace
    - *It depends of the flight level*
      - **FL270** -> Upper airspace
    - *Use a route calculator*
      - **Route**: LEMD, PINAR, SEGRE, BRITO , PISUS, PONEN, CASPE, LEBL
    - *Airways are (or used to be…) determined by the available navaids*
    - ***Chart**: Upper Airspace*
      - Airways UN870, UW800

Planning a Madrid-Barcelona flight

- **En-route phase**

Upper Airspace Chart



PINAR 1er wpt.

CASPE last waypoint

Departure **CRUISE** **ARRIVAL** **APP.**

Planning a Madrid-Barcelona flight

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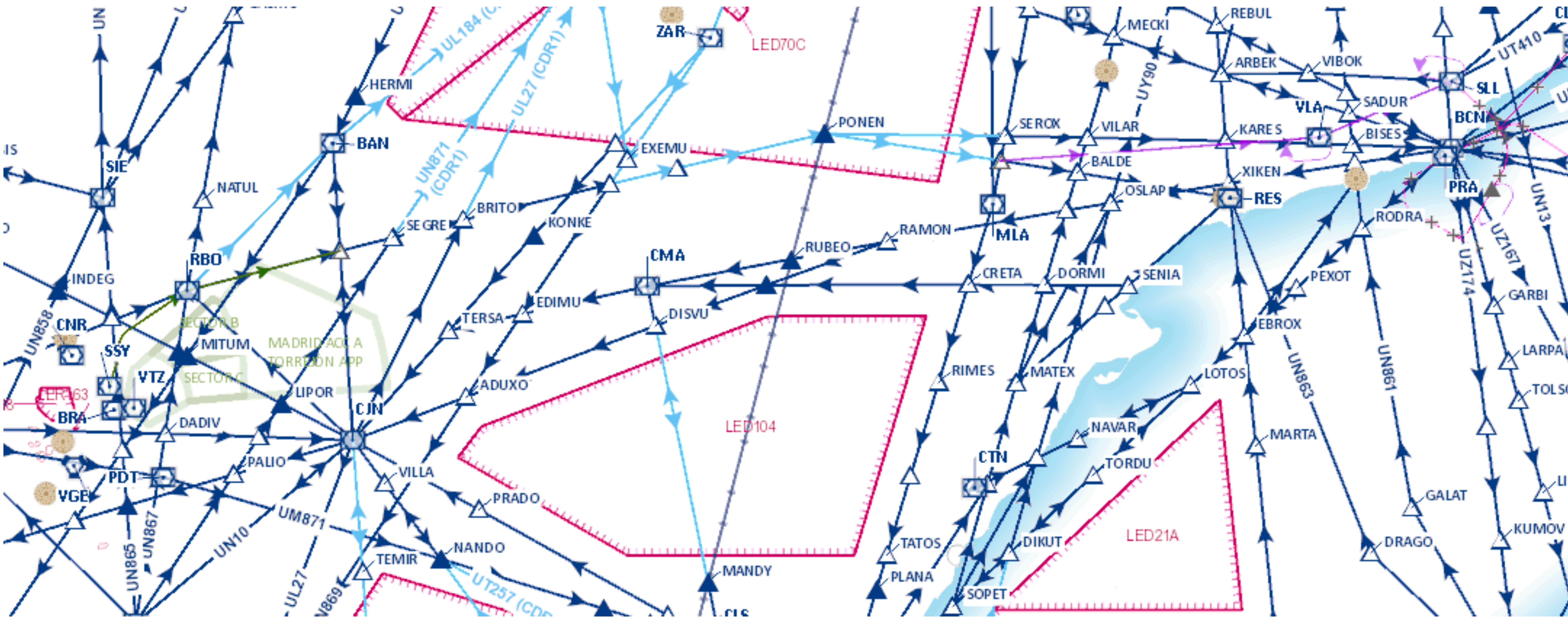
- **En-route phase**
  - ✦ Insignia website: https://ais.enaire.es/insignia/navegador/



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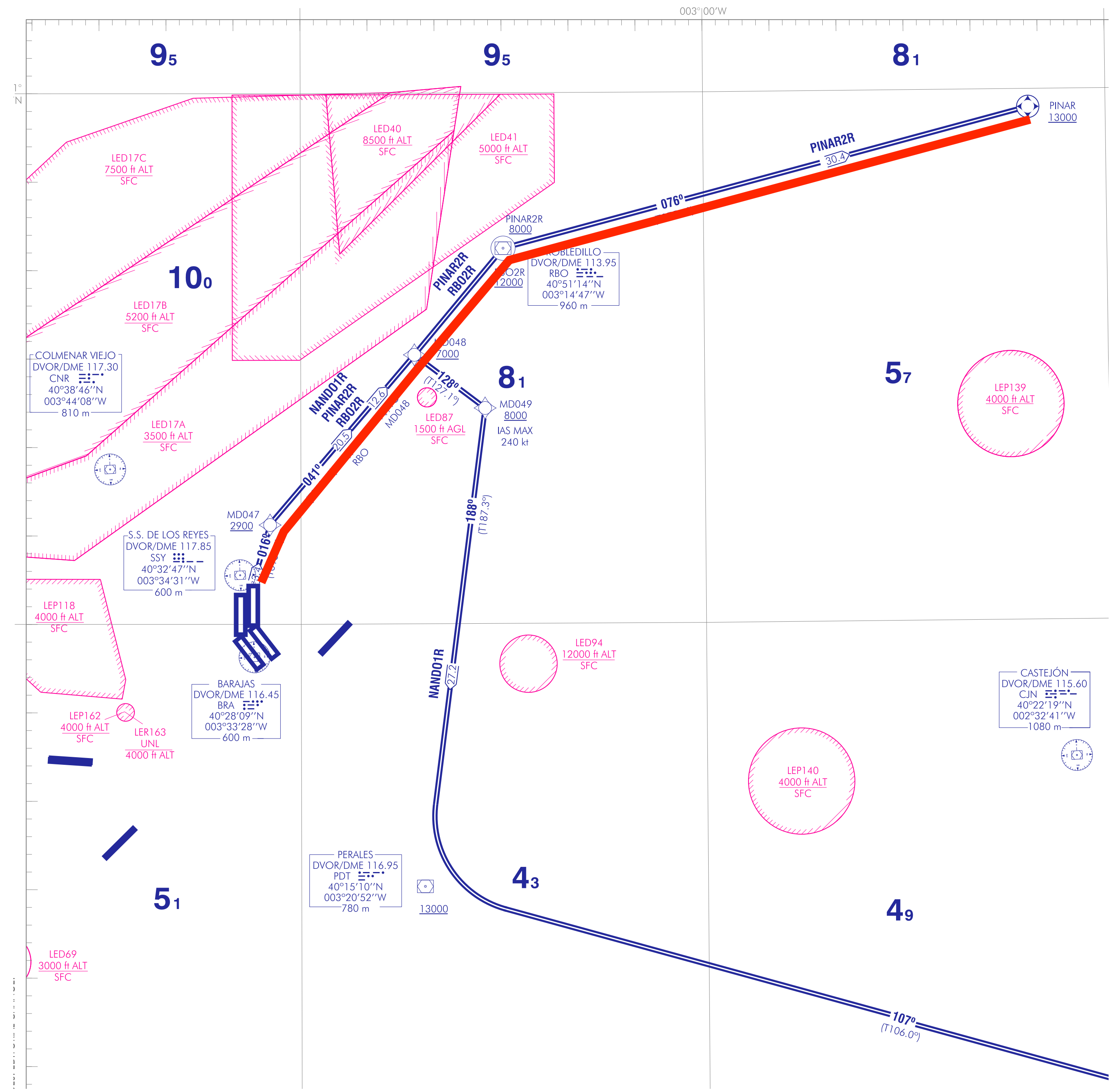
Planning a Madrid-Barcelona flight

- **SID - Standard Instrument Departure**
  - ✦ It mainly depends on the take-off runway and the 1st waypoint en route
  - ✦ **Chart**: SID Madrid-Barajas RWY 36L Diurno
    - *Departure* ***PINAR 2R***



Planning a Madrid-Barcelona flight

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SID - Standard Instrument Departure

- Flight procedure description

AD 2-LEMD SID 12.4 AIP
WEF 20-JUN-19 ESPAÑA

SALIDAS NORMALIZADAS POR INSTRUMENTOS (SID)
STANDARD INSTRUMENT DEPARTURES (SID)

DESCRIPCIÓN FORMAL FORMAL DESCRIPTION	DESCRIPCIÓN ABREVIADA ABBREVIATED DESCRIPTION	Código Path Terminator Previsto Expected Path Terminator Coding	Fly-Over Requerid Fly-Over Required
PINAR2R RNAV1 (DME/DME) Pendiente mínima de ascenso: 5.5% hasta 5500 ft. // Minimum climb gradient of 5.5 % up to 5500 ft. Pendiente mínima de ascenso: 5.0% desde 5500 ft hasta RBO. // Minimum climb gradient of 5.0 % from 5500 ft up to RBO. Pendiente mínima de ascenso: 3.3% desde RBO hasta PINAR. // Minimum climb gradient of 3.3% from RBO up to PINAR.			
A MD047 en rumbo 016ºM a o por encima de 2900 ft, viraje a la derecha. A <u>RBO</u> a o por encima de 8000 ft, viraje a la derecha. A <u>PINAR</u> a o por encima de 13000 ft. To MD047 on heading 016ºM at or above 2900 ft, turn right. To <u>RBO</u> at or above 8000 ft, turn right. To <u>PINAR</u> at or above 13000 ft.	MD047 [M016;A2900+;R] - <u>RBO</u> [A8000+;R] - <u>PINAR</u> [A13000+]	CF TF TF	- Y Y
RBO2R RNAV1 (DME/DME) Pendiente mínima de ascenso: 6.9 % hasta 12000 ft. // Minimum climb gradient of 6.9 % up to 12000 ft.			
A MD047 en rumbo 016ºM a o por encima de 2900 ft, viraje a la derecha. A <u>RBO</u> a o por encima de 12000 ft. To MD047 on heading 016ºM at or above 2900 ft, turn right. To <u>RBO</u> at or above 12000 ft.	MD047 [M016;A2900+;R] - <u>RBO</u> [A12000+]	CF TF	- Y

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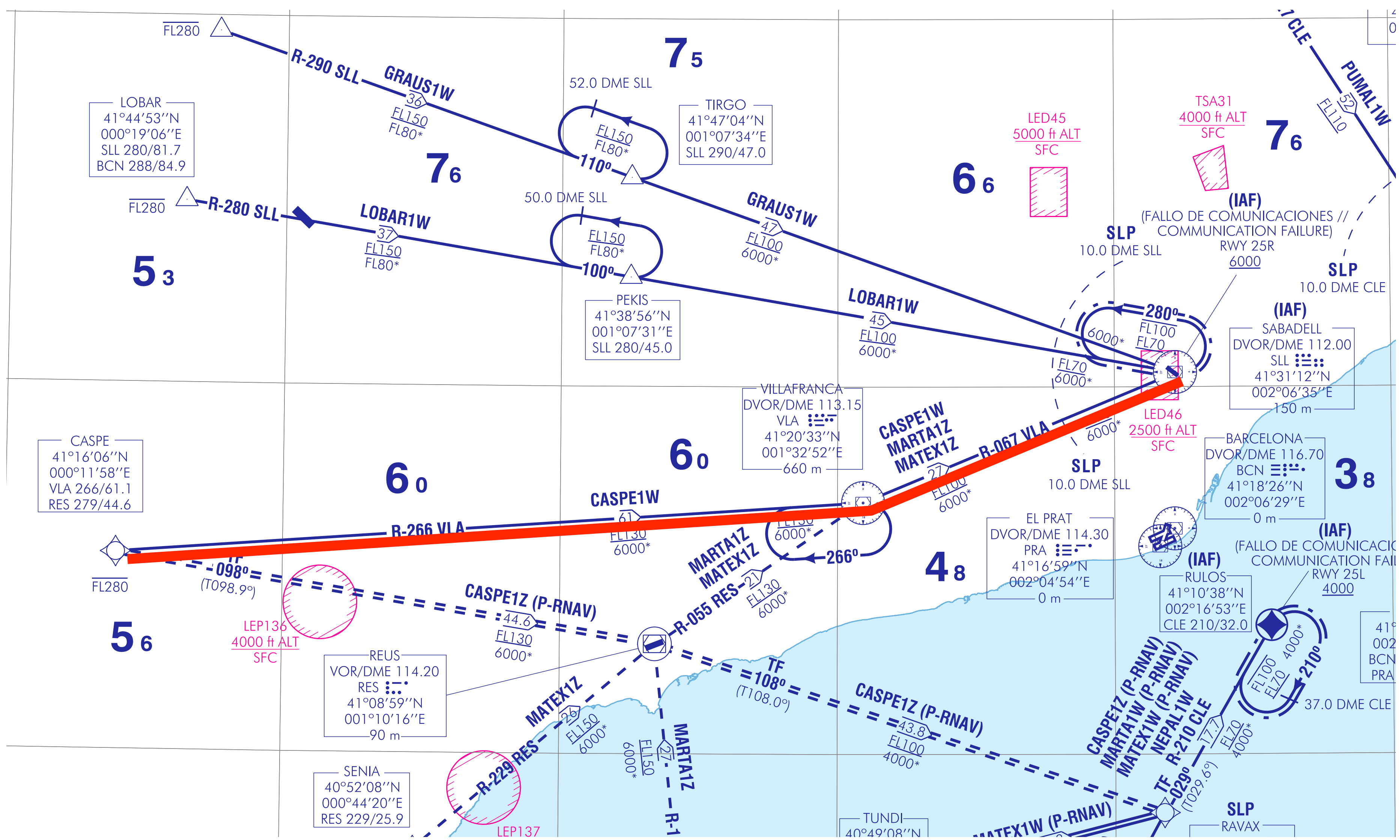
STAR - Standard Arrival

- ✦ It mainly depends on the last waypoint en route, the landing runway, the IAF, and the navigation instruments used for the approach.
- ✦ **Chart**: STAR Barcelona RWY 25R/25L
  - *CASPE 1W with conventional instruments*



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Planning a Madrid-Barcelona flight

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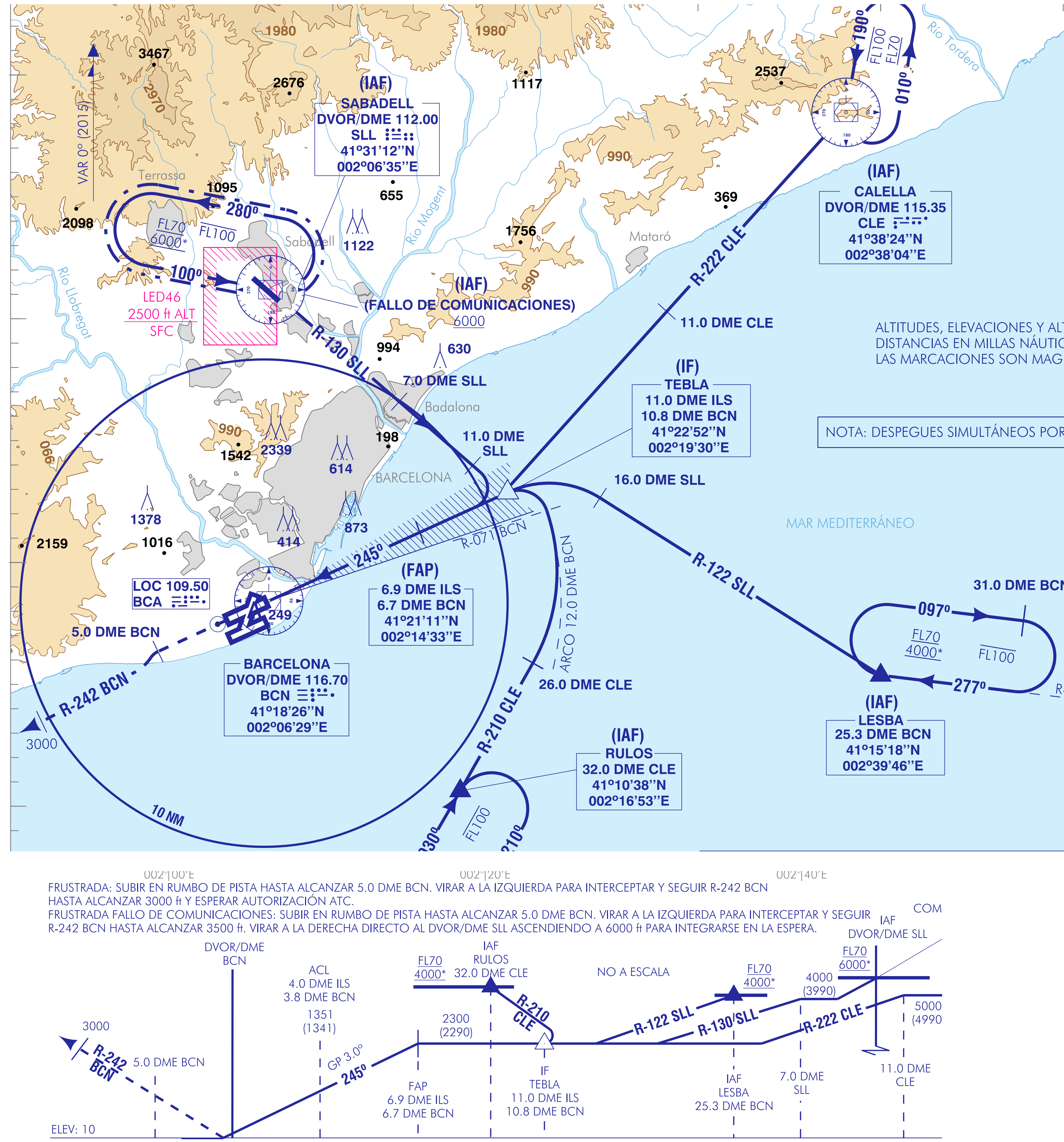
Approach

- It mainly depends on the runway and the navaid use to land
- The preferred approach is using the ILS navaid:
  - *Chart: IAC ILS RWY 25R*



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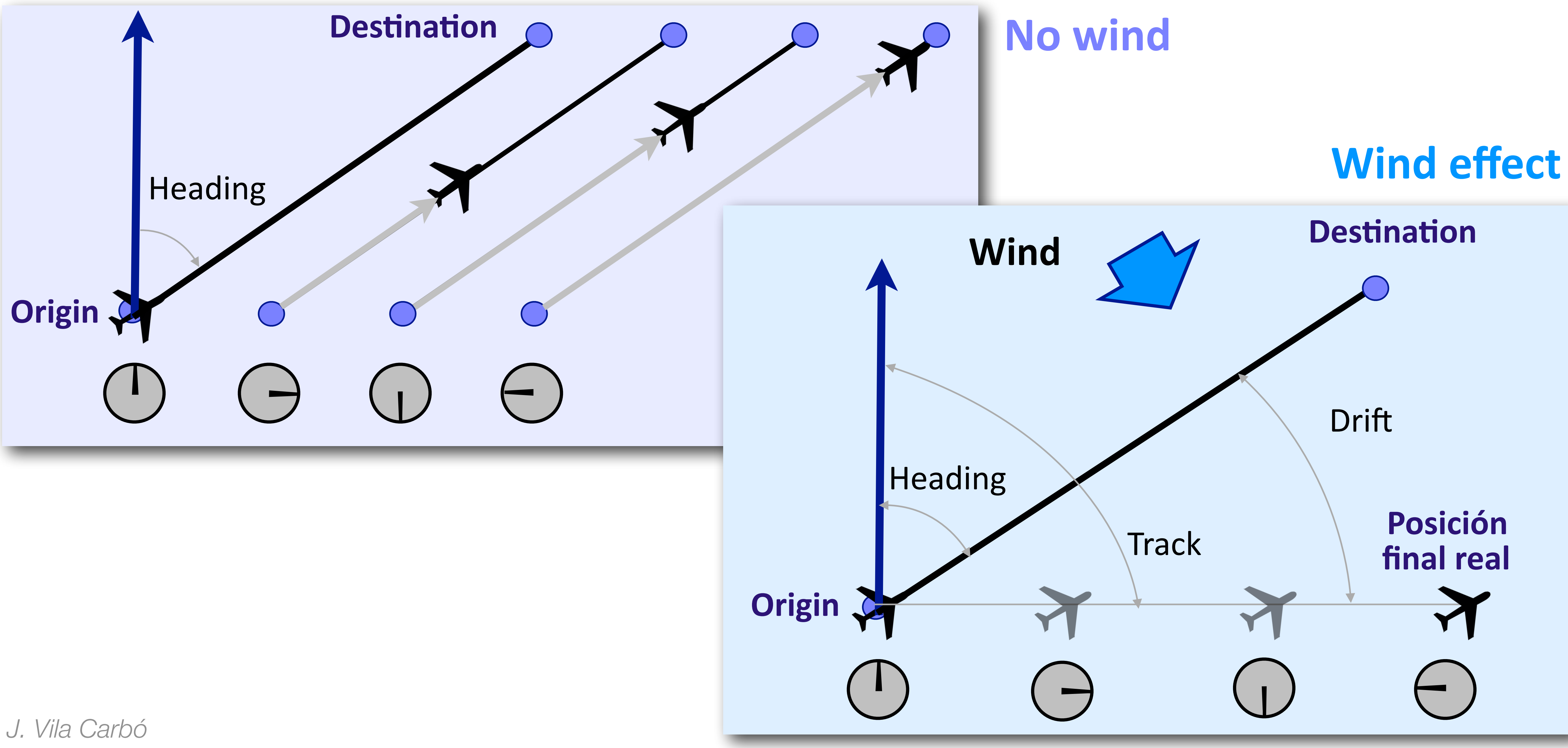
The wind triangle

Wind effect on trajectories

- Wind causes a deviation in the trajectory of an aircraft. The true trajectory course is given by the **track *(derrota)*** and does no longer follow the **heading** course. There is a **drift** between both angles.

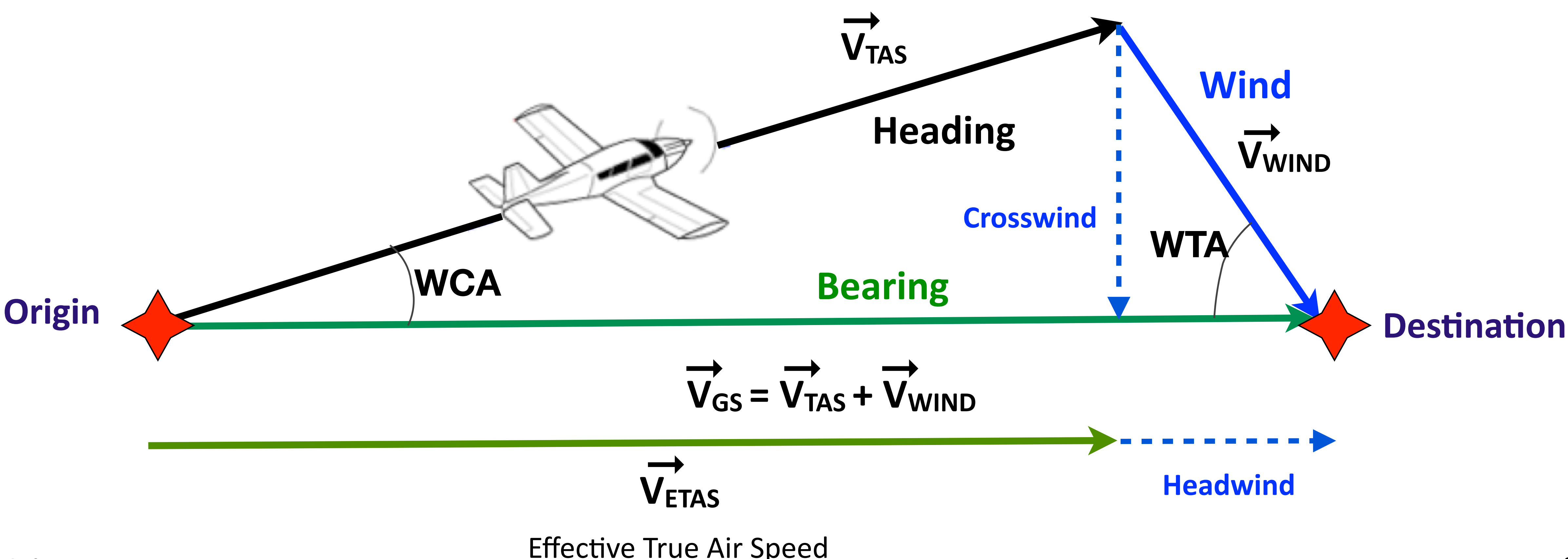


The wind triangle

Wind triangle vectors

- **GS** - Ground Speed: vectorial sum of:
- **TAS** - True Air Speed: relative speed of aircraft to airmass
- **Wind Speed**: two components
  - *Crosswind*
  - *Headwind*

WCA= Wind Correction Angle
WTA=Wind to track Angle



The wind triangle

The wind triangle

- It is a graphical representation of the relationship between aircraft motion and wind. It is used extensively in dead reckoning navigation.
- The wind triangle is a vector diagram, with three vectors.
  - *The **true airspeed** represents the motion of the aircraft through the airmass. It is described by its magnitude and true heading.*
  - *The **wind vector** represents the motion of the airmass over the ground. It is described by wind speed and the inverse of wind direction.*
    - By convention wind direction is given as the direction the wind is from.
  - *The **ground speed** vector represents the motion of the aircraft over the ground. It is described by ground track and ground speed. It is the vectorial sum of the true airspeed and the wind vector.*

The wind triangle

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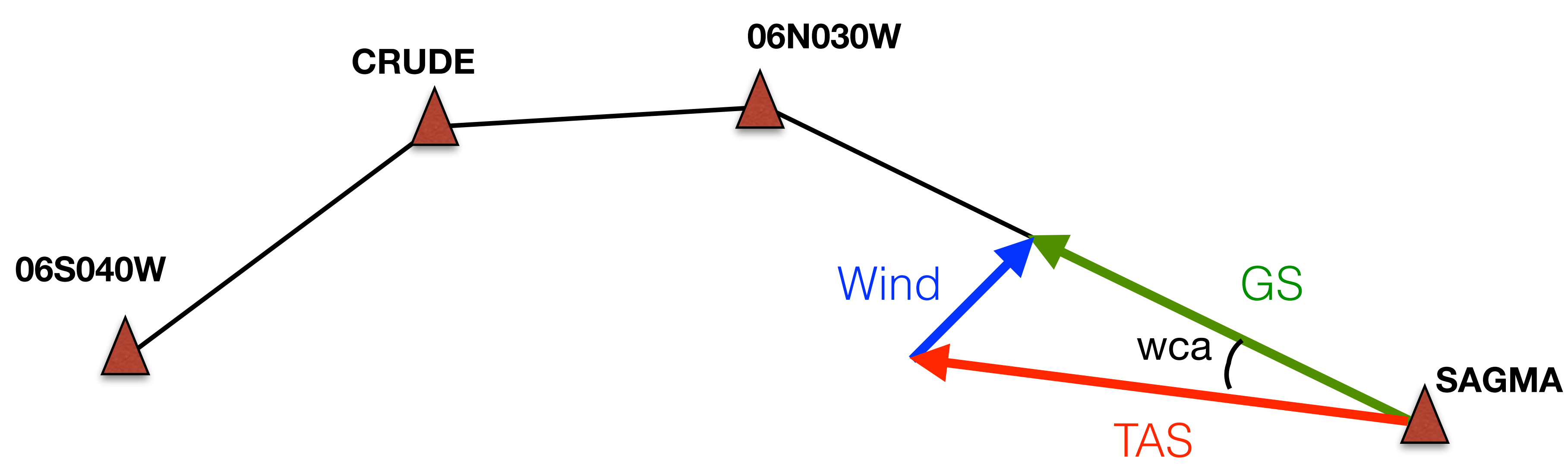
Solving the wind triangle

- The three principal types of problems to solve are:
- **Solve for the ground vector**. This type of problem arises when true heading and true airspeed are known by reading the flight instruments and when wind direction and speed are known from either the meteorological forecast or from determination in flight.
- **Solve for the wind vector**. This type of problem arises when determination of heading and true airspeed can be done by reading the flight instruments and ground track and ground speed using GPS or either by
  - *Measuring the direction and distance between two established points of the aircraft or by*
  - *Determining the drift angle and ground speed by reference to the ground.*
- **Solve for true heading and ground speed**. This type of problem arises during flight planning or during a flight, when there is a need to determine a true heading to fly and a ground speed with which to compute an estimated time of arrival.

The wind triangle

Solving the wind triangle

- In a route the known data are usually the TAS module, track angle and wind estimation.
- The autopilot has to solve for GS and WCA (Wind Correction Angle)



wca: wind correction angle

The wind triangle

Solving the wind triangle

- **4 values as input**: Wind direction, Wind speed, Airspeed and Desired Course Angle.
- **Wind Direction Adjustment**
  - *WindDir = Input WindDirection +180°*
    - Since Wind directions are given as "From" direction rather than "To", we'll add 180 degrees to get our vector point in the correct (downwind) direction..
- **Wind To Track Angle**
  - *WTAngle = DesiredCourse - WindDir*
    - The input angles Wind direction (WinDir) and Desired Course (DesiredCourse) are fixed angles independent of any other values. The difference is calculated as a convenience in references in the equations below.
- **Wind Correction Angle**
  - *sinWCA:=windspeed*sin(WTAngle)/Airspeed;*
  - *WCA:=arcSin(sinWCA);*
    - We'll define the Wind Correction Angle (WCA) to be the angle that our Heading Angle must deviate from the DesiredCourse to correct for the effect the the Wind is having on our aircraft.

The wind triangle

Solving the wind triangle (ii)

Heading

- *Heading:=DesiredCourse+WCA;*
  - By definition the Wind Correction Angle is the angle between the Heading and the Desired Course: WCA = Heading - DesiredCourse which leads directly to the above equation.

Groundspeed

- *groundspeed = airspeed*cos(WCA) + windspeed*cos(WTAngle)*

The wind triangle

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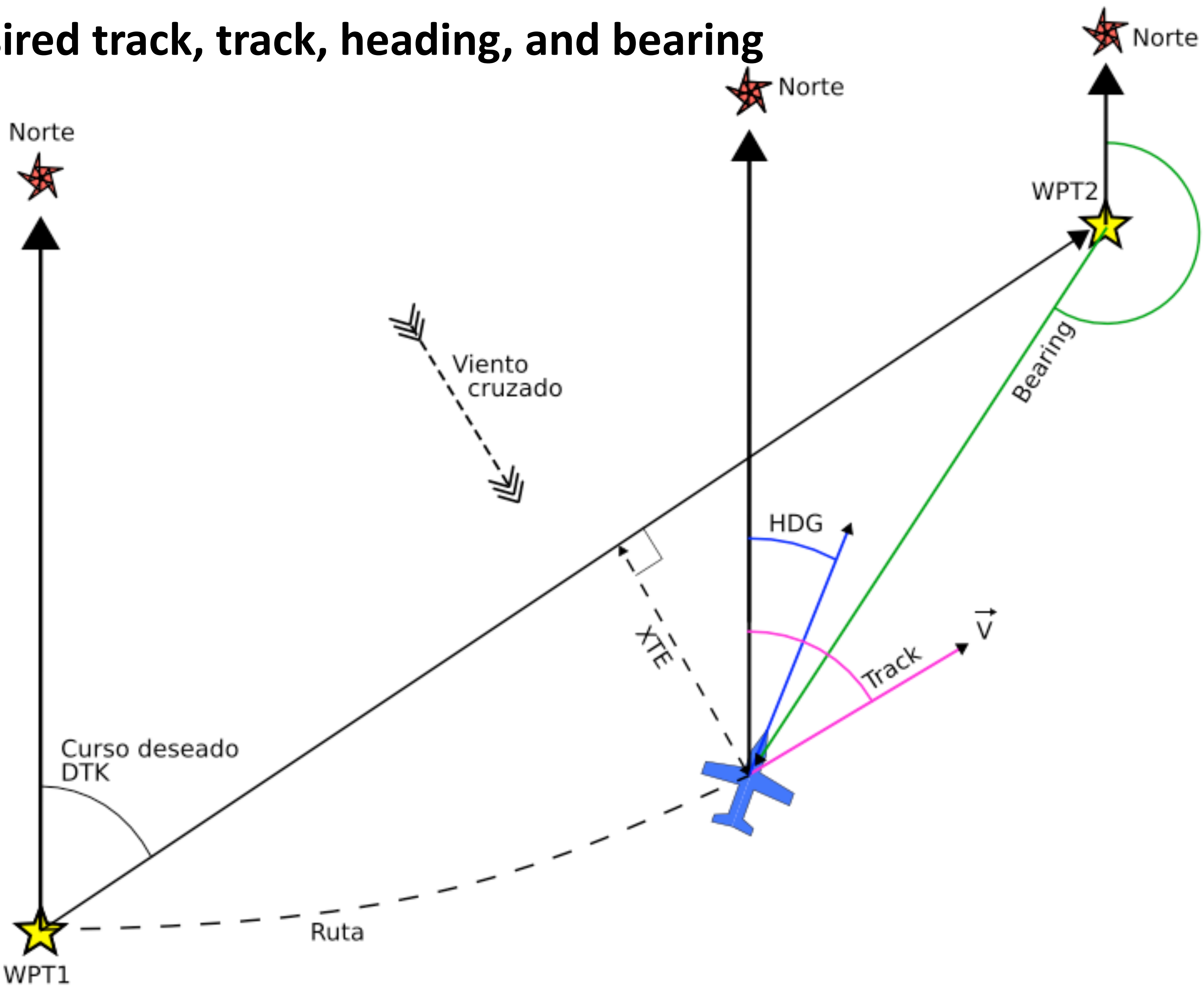
Desired track, track, heading, and bearing

- **Desired Track / DTK**: angle between the N and the line connecting two successive waypoints in the route.
- **Track / TK**: (*derrota*) angle between the north and the velocity vector.
- **Cross-Track Error / XTE**: distance between the position of the aircraft and the line representing the desired track.
  - *The difference between the desired path (DTK) and the path actually followed (TK) is due to external factors such as crosswind.*
- **Heading / HDG**: angle between the N and the longitudinal axis of the aircraft.
  - *Not necessarily matches the velocity vector (Track) course since it may occurr that, for example, the pilot changes the course to compensate for a crosswind.*
- **Bearing**: (*marcación*) angle between the N and a straight line connecting the aircraft and a external reference. Often the reference is a beacon.

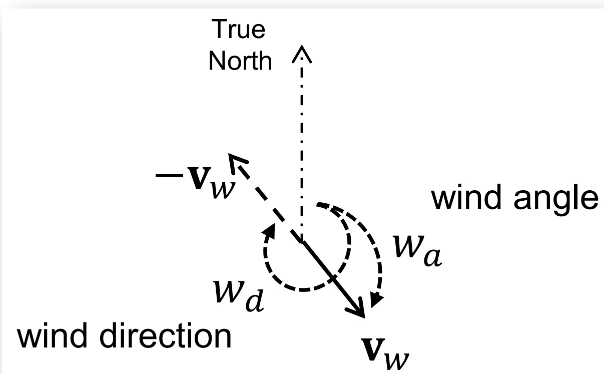
The wind triangle

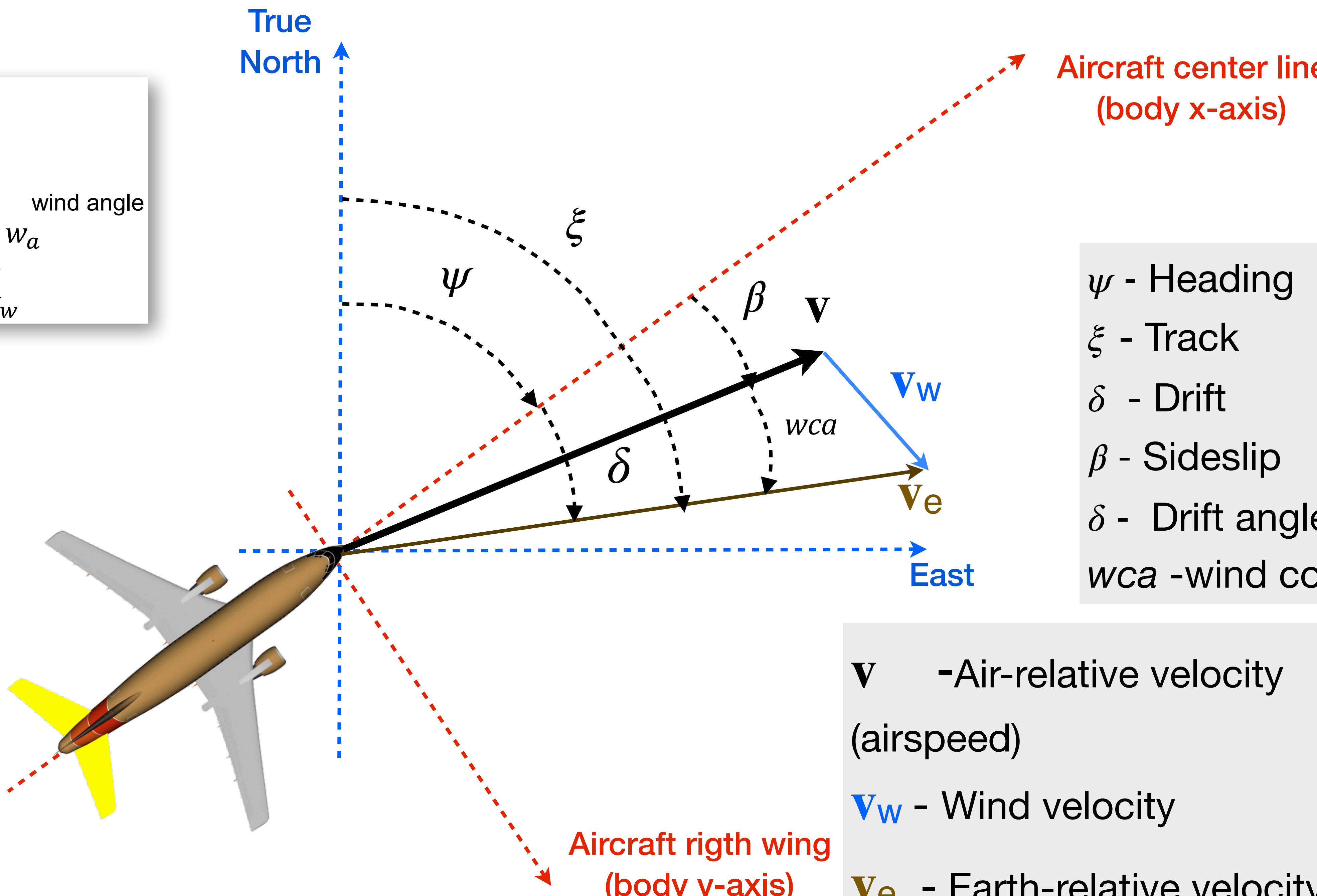
- **Desired track, track, heading, and bearing**



The wind triangle

Velocities and angles





ψ - Heading

ξ - Track

δ - Drift

β - Sideslip

δ - Drift angle

wca -wind correction

$\mathbf{v}$ -Air-relative velocity (airspeed)

$\mathbf{v}_\mathrm{w}$ - Wind velocity

$\mathbf{v}_\mathrm{e}$ - Earth-relative velocity

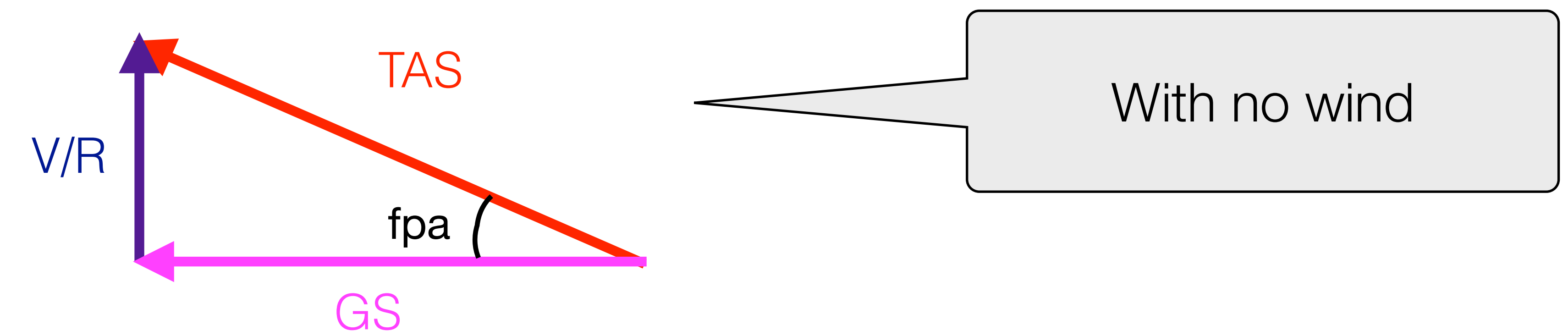
Flight planning

- **Introduction**
- **Flight phases**
- **Planning a Madrid-Barcelona flight**
  - En-route
  - SID - Standard Instrument Departure
  - STAR - Standard Arrival
  - IAC - Instrument Approach
- **The wind triangle**
- **The vertical profile**

The vertical profile

The vertical profile

- The vertical profile requires determining the **altitudes** and **vertical rates** (V/R) of each waypoint.
- Altitude limitations are given by the charts.
- Vertical rates are mainly given by the manufacturer recommendations of the operation manual. But they are also available in some databases:
  - ***Eurocontrol BADA model***
    - Requires Eurocontrol user and permission.



fpa: flight path angle

The vertical profile

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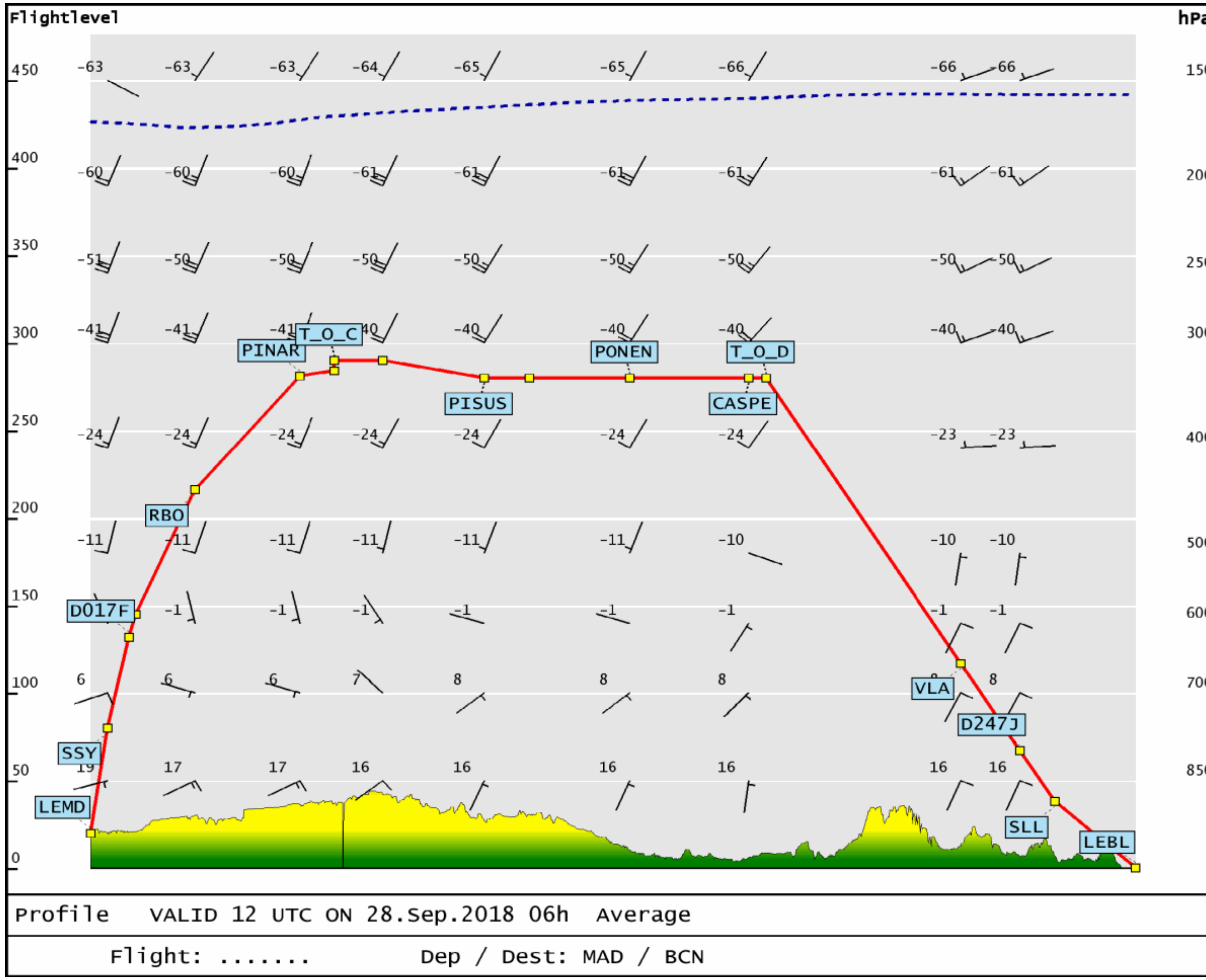
Vertical profile example

- Madrid-Barcelona flight



The vertical profile

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Eurocontrol BADA model

✦ The vertical profile highly depends on the aircraft performance.

EUROCONTROL

See BADA APF and PTF Files

4.1. CLIMB

The following parameters are defined for each aircraft type to characterise the climb phase:

$V_{cl,1}$	-	standard climb CAS [knots] between 1,500/6,000 and 10,000 ft
$V_{cl,2}$	-	standard climb CAS [knots] between 10,000 ft and Mach transition altitude
M_{cl}	-	standard climb Mach number above Mach transition altitude

- For jet aircraft the following CAS schedule is assumed, based on the parameters mentioned above and the take-off stall speed:

from 0 to 1,499 ft	$C_{Vmin} \cdot (V_{stall})_{TO} + Vd_{CL,1}$	(4.1-1)
from 1,500 to 2,999 ft	$C_{Vmin} \cdot (V_{stall})_{TO} + Vd_{CL,2}$	(4.1-2)
from 3,000 to 3,999 ft	$C_{Vmin} \cdot (V_{stall})_{TO} + Vd_{CL,3}$	(4.1-3)
from 4,000 to 4,999 ft	$C_{Vmin} \cdot (V_{stall})_{TO} + Vd_{CL,4}$	(4.1-4)
from 5,000 to 5,999 ft	$C_{Vmin} \cdot (V_{stall})_{TO} + Vd_{CL,5}$	(4.1-5)
from 6,000 to 9,999 ft	$\min(V_{cl,1}, 250\text{ kt})$	
from 10,000 ft to Mach transition altitude	$V_{cl,2}$	
above Mach transition altitude	M_{cl}	

The vertical profile

Eurocontrol BADA model

- The vertical profile highly depends on the aircraft performance.

6.6. PTF FILE FORMAT

The Performance Table File (PTF) is an ASCII file, which for a particular aircraft type specifies cruise, climb and descent performance at different flight levels. An example of a PTF file for the Airbus A306 aircraft is shown below.

```
                              BADA PERFORMANCE FILE        Apr 23 2002

AC/Type: A306
                              Source OPF File:              Mar 26 2002
                              Source APF file:              Mar 26 2002

 Speeds:   CAS(LO/HI)  Mach   Mass Levels [kg]        Temperature:   ISA
 climb   - 250/300     0.79   low     - 104400
 cruise  - 250/310     0.79   nominal - 140000        Max Alt. [ft]:  41000
 descent - 250/280     0.79   high    - 171700
==========================================================================================
 FL |          CRUISE           |             CLIMB                |        DESCENT
    |  TAS          fuel        |  TAS      ROCD            fuel   |  TAS  ROCD    fuel
    | [kts]       [kg/min]      | [kts]     [fpm]         [kg/min] | [kts] [fpm] [kg/min]
    |          lo    nom    hi  |        lo   nom   hi     nom     |        nom    nom
==========================================================================================
  0 |                           |  157   2210 1990 1620   270.3    |  131   760    97.2
    |                           |                                  |
  5 |                           |  158   2190 1970 1600   267.3    |  132   780    96.1
    |                           |                                  |
 10 |                           |  159   2170 1950 1570   264.3    |  138   800    95.0
    |                           |                                  |
 15 |                           |  166   2290 2030 1650   261.5    |  149   850    94.0
    |                           |                                  |
 20 |                           |  167   2270 2010 1620   258.5    |  181  1020    31.0
    |                           |                                  |
 30 |  230     61.2  81.4 104.3 |  190   2750 2360 1920   253.0    |  230  1360    25.0
    |                           |                                  |
```

The vertical profile

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Eurocontrol BADA model

FL	CRUISE TAS [kts]	CRUISE fuel [kg/min] lo	CRUISE fuel [kg/min] nom	CRUISE fuel [kg/min] hi	CLIMB TAS [kts]	CLIMB ROCD [fpm] lo	CLIMB ROCD [fpm] nom	CLIMB ROCD [fpm] hi	CLIMB fuel [kg/min] nom	DESCENT TAS [kts]	DESCENT ROCD [fpm] nom	DESCENT fuel [kg/min] nom
40	233	61.2	81.4	104.4	225	3350	2780	2270	247.7	233	1380	24.5
60	272	65.9	81.7	99.6	272	4210	3070	2370	236.8	240	1410	23.3
80	280	65.8	81.7	99.7	280	4040	2930	2230	225.7	280	1550	22.1
100	289	65.8	81.7	99.8	289	3860	2780	2090	214.8	289	1590	20.9
120	297	65.7	81.7	99.8	356	3820	2800	2170	204.8	332	1880	19.8
140	306	65.6	81.7	99.9	366	3590	2610	2000	194.3	342	1920	18.6
160	389	82.4	93.1	105.3	377	3360	2410	1820	184.1	353	1960	17.4
180	401	82.1	92.9	105.1	388	3120	2220	1650	174.2	363	2000	16.2
200	413	81.7	92.6	104.9	400	2880	2020	1470	164.5	375	2040	15.1
220	425	81.3	92.3	104.7	412	2630	1810	1290	155.0	386	2080	13.9
240	438	80.9	91.9	104.5	425	2380	1610	1100	145.8	398	2120	12.7
260	452	80.4	91.6	104.3	438	2130	1400	920	136.9	411	2160	11.6
280	466	79.9	91.2	104.1	452	1880	1200	730	128.1	424	2200	10.4
290	468	78.4	90.1	103.4	459	1760	1090	640	123.9	431	2220	9.8
310	464	74.3	87.0	101.5	464	2200	1290	660	115.4	444	2250	8.6
330	459	70.6	84.7	100.6	459	1950	1050	420	107.2	459	2290	7.4
350	455	67.6	83.0	97.9	455	1700	810	170	99.2	455	3150	6.3

EUROCONTROL

The vertical profile

- **Calculating the vertical profile**

    1. Choose an en-route altitude. Consider that all en-route waypoints have the same altitude. It has to be a “feasible” altitude.
    2. Set the altitude limits for the waypoints of the climb and the descent phases. as specified by the charts.
    3. Select a True Airspeed. (TAS) and an altitude for each waypoint taking into account the BADA database.
    4. Solve the speeds triangle in the vertical profile of figure 5 and calculate the FPA (Flight Path Angle), the GS (without wind, it is the horizontal projection of TAS), and the vertical rate V/R.
    5. If the calculated vertical speed V/R is in the recommended range for the ROCD (Rate Of Climb or Descent) given by the PTF file of BADA for that aircraft and altitude, then the leg is correctly calculated. If not you will need to readjust some altitude or speed values and to start a new iteration.

The vertical profile

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Piloting the vertical profile

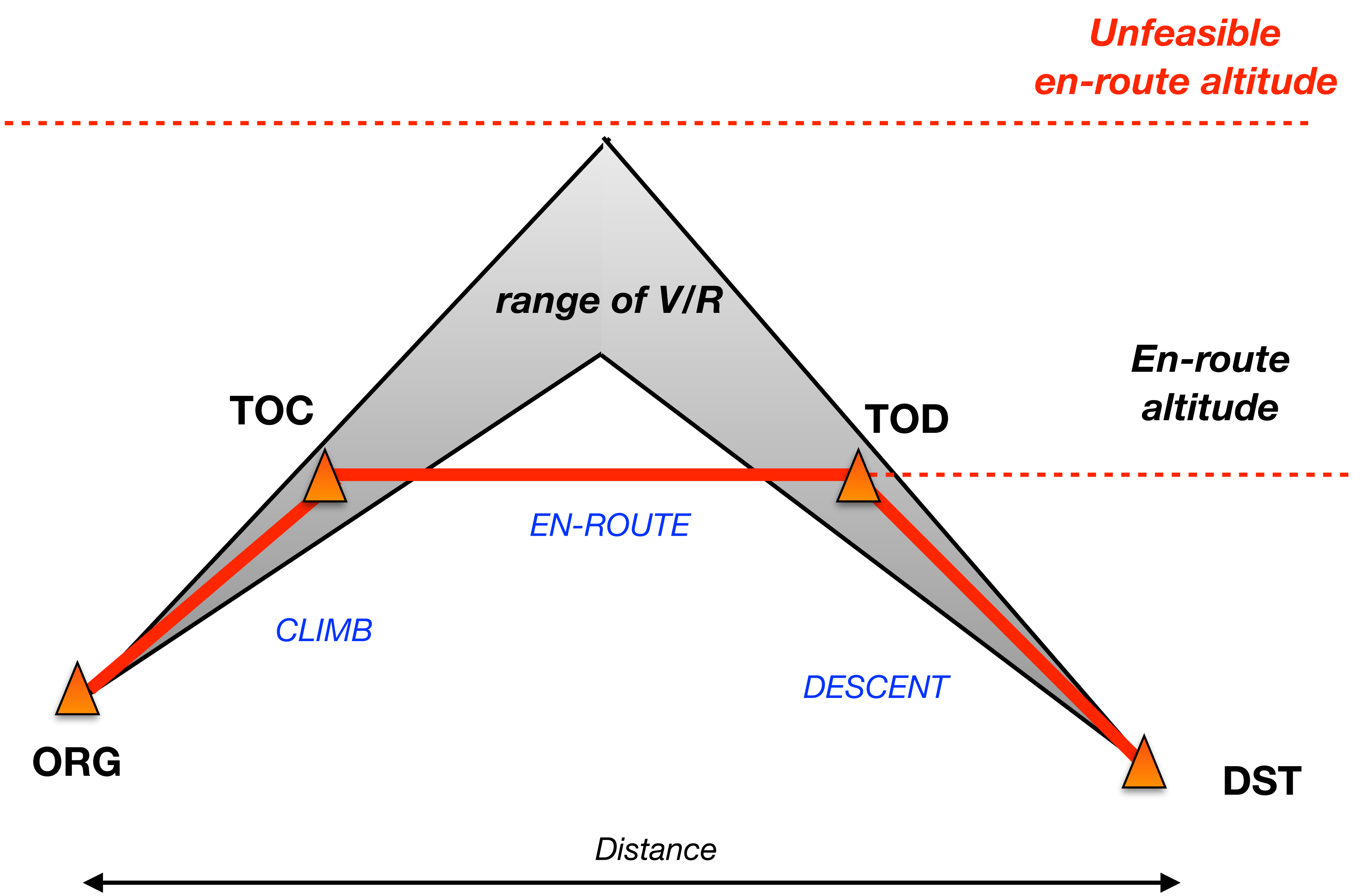
- For piloting the vertical profile the pilot can act on **Throttle** and **elevators**.
- But it usually pilots using the A/P (Auto Pilot) where it can set **two** out of the **three** following values:
  - ***SPD*** *- Desired speed*
  - ***V/R*** *- Desired V/R*
  - ***Throttle*** *- Throttle lever*
- 2 DOFs (Degrees Of Freedom): the third value is given by the *Total Energy Balance*:

$$(Thr - D) \cdot V_{TAS} = mg_0 \frac{dh}{dt} + mV_{TAS} \frac{dV_{TAS}}{dt}$$

Excess Energy | **Potential Energy Variation** | **Kinetic Energy Variation**

The vertical profile

- **Choosing the en route altitude**
  - ✦ Try to minimise consumptions
  - ✦ Take into account distance between ORG and DST



The vertical profile

Piloting the vertical profile

- The MCP (Mode Control Panel) of the B737.

Speed

A/T
Autothrottle

Heading

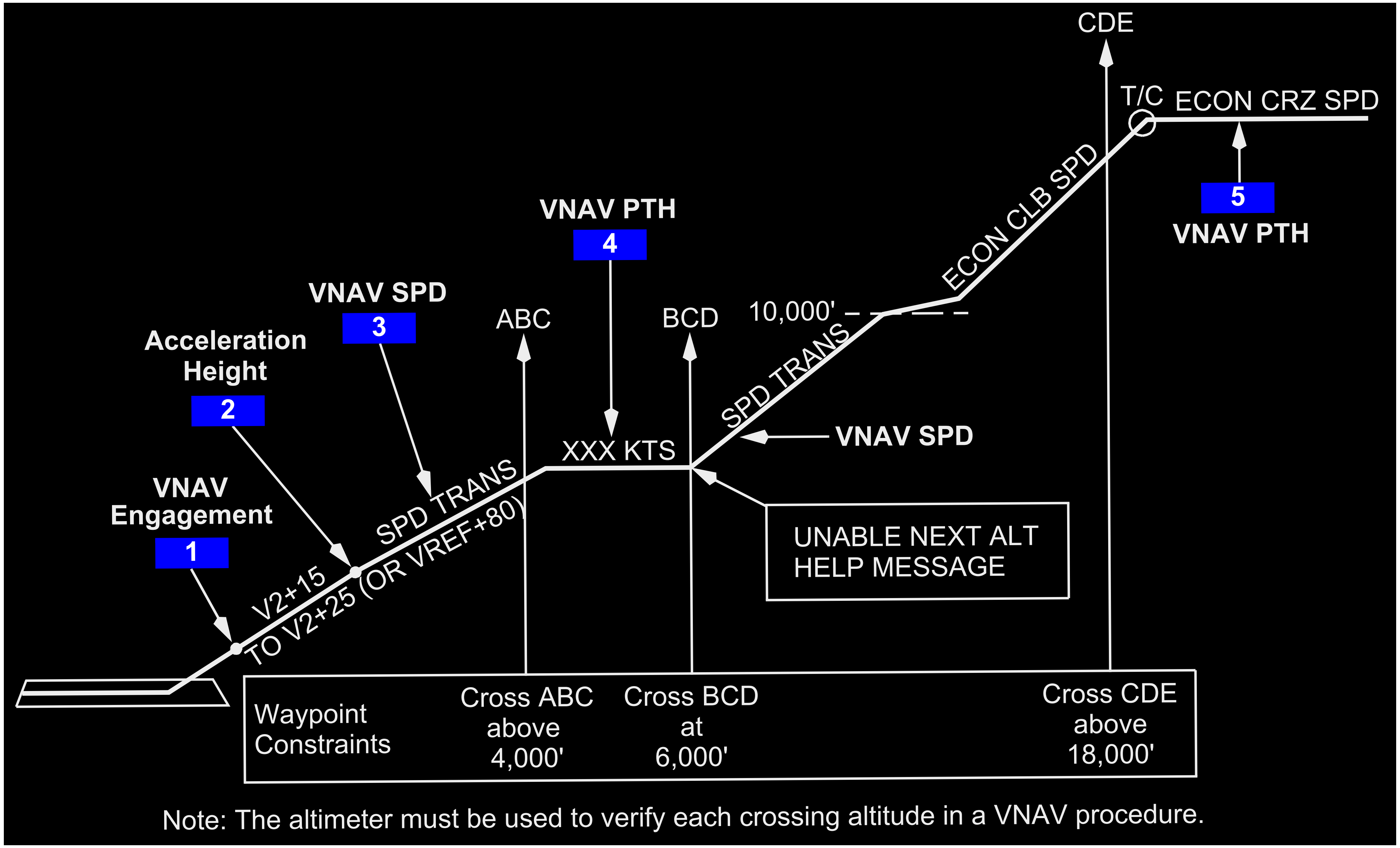
Altitude & Vertical

Throttle

The vertical profile

Take-off and climb profile

- It contains **acceleration legs**, **constant speed legs** (VNAV SPD), and **legs with geometric path** which require a FPA (Flight Path Angle) =0 (VNAV PTH).



The vertical profile

Take-off and climb profile

1 Takeoff

If armed for takeoff, VNAV activates at 400 feet RA and pitch guidance continues to maintain the target airspeed.

During takeoff, the FMC updates the target airspeed to the current airspeed until VNAV activates. The target airspeed is between V2 + 15 and V2 + 25 knots.

2 Acceleration Height

At acceleration height or flap retraction, VNAV commands an airspeed increase to a speed 5 knots below the flap placard speed for the existing flap setting. When flaps are retracted or at an AFDS capture altitude, VNAV commands the greater of VREF + 80 knots or the speed transition associated with the origin airport, limited by configuration.

The FMC changes the thrust reference mode to the selected climb thrust at the thrust reduction point.

3 VNAV Climb

The VNAV climb profile uses VNAV SPD or VNAV PTH at the default climb speed or pilot selected climb speed to remain within all airspeed and altitude constraints that are part of the SID entered into the active route. Autothrottle uses selected climb thrust limit.

If the climb speed profile cannot achieve an altitude constraint, the UNABLE NEXT ALT CDU help window message displays.

The vertical profile

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Take-off and climb profile

4 Climb Constraints

VNAV enters the VNAV PTH mode to remain within departure or waypoint constraints. Speed maintained during this time can be:

- procedure based speed restriction
- waypoint speed restriction
- default VNAV climb speed
- manually entered climb speed

If the FMC predicts the airplane will not reach an altitude constraint, the FMS–CDU help window message UNABLE NEXT ALTITUDE displays. Speed intervention can be used by pushing the IAS/MACH selector and manually setting a lower airspeed to provide a steeper climb; or, climb derates can be deleted on the THRUST LIMIT page.

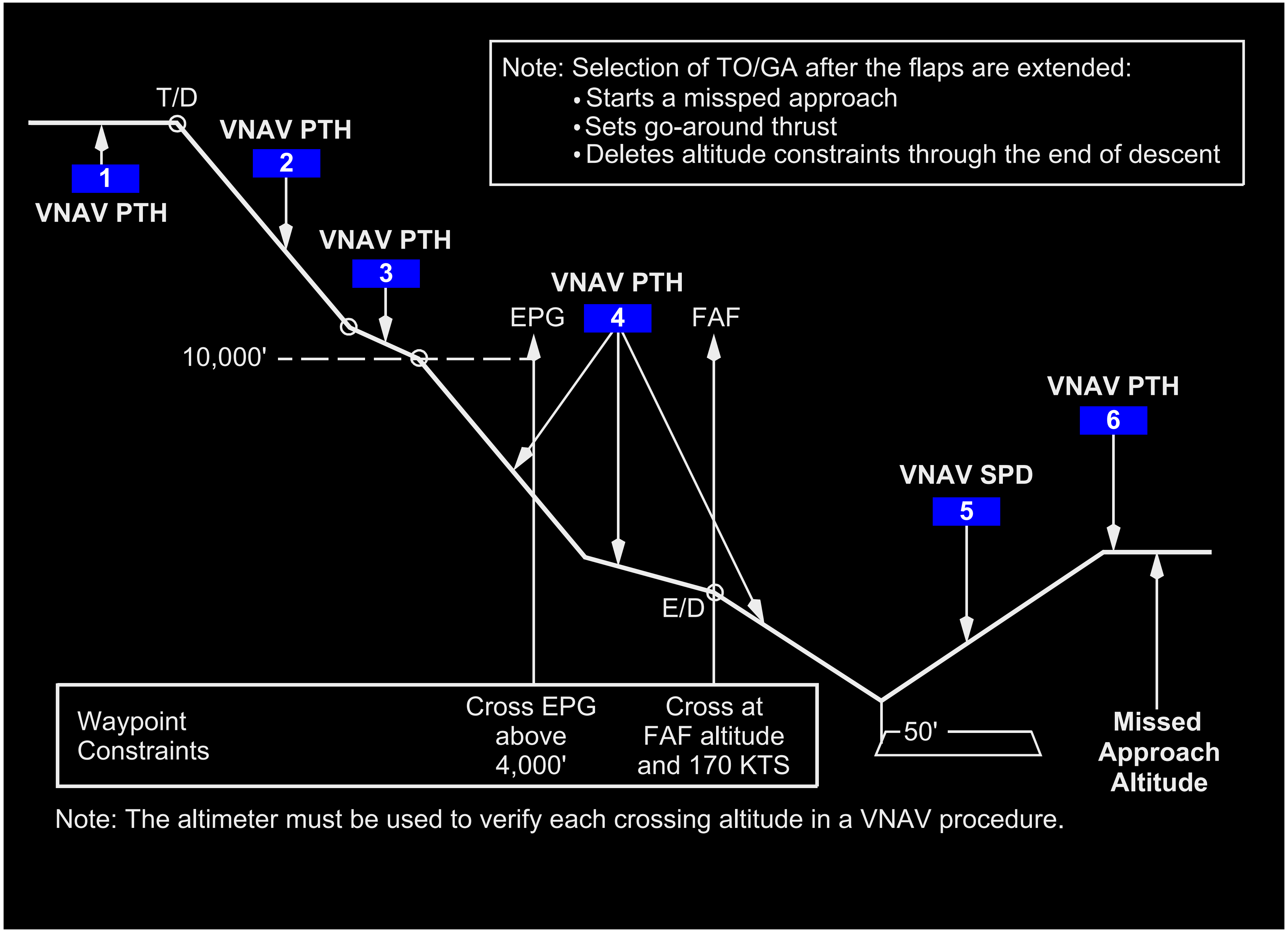
5 Top Of Climb (T/C)

The point where the climb phase meets the cruise altitude is called the top of climb. Approaching this point, the FMC changes from the climb phase to the cruise phase. The T/C displays any time the FMC calculates a change from a climb phase to a cruise phase, such as a step climb.

The T/C point displays on the map as a green open circle with the label T/C.

The vertical profile

Descent and landing profile



The vertical profile

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Descent and landing profile

1 Cruise

Before the top of descent, FMC is in cruise mode and commands VNAV PTH and ECON cruise speed.

2 Descent

Nearing descent speed, VNAV commands a descent in VNAV PTH at ECON descent speed.

3 Descent Deceleration Phase

Before the speed restriction altitude, the FMC commands the target descent airspeed. The pitch mode remains VNAV PTH and the descent rate approximates 500 feet per minute.

4 Descent and Approach

When at target speed, VNAV commands a descent and starts approach in VNAV PTH at commanded speed.

5 Missed Approach

When selected during missed approach, VNAV activates in VNAV SPD.

6 Missed Approach Level Off

At missed approach altitude, VNAV SPD changes to VNAV PTH.