GNSS in aviation

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Outline

Overview

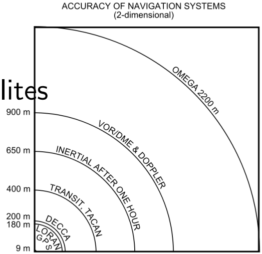
GNSS stands for

- **G**lobal
- **N**avigation
- **S**atellite
- **S**ystem

- GNSS is a system of satellites that provides autonomous geo-spatial positioning with global coverage
- GNSS is a term that covers the whole range of implementations
- GNSS systems are similar to the ground-based navigation aids but are located outside of the terrain interference
- GNSS includes ground support and various augmentations to improve integrity and accuracy.

Overview

- Early predecessors used terrestrial radio transmitters
- First GNSS: Transit, 1960
- Modern navigational systems use dozens of satellites
- World of GNSS:
    - GPS (USA)
    - GLONASS (Russia)
    - Compass (China)
    - Galileo (EU)
- Only GPS and GLONASS are fully operational



Navigation glossary

- **Course** is the angle that the intended path of the aircraft makes with a fixed reference object (for example, magnetic north)
- **Heading** is the angle of the aircraft to a fixed reference object (for example, magnetic north)
- **Bearing** is the direction from us to another object
- **Track** or course over ground, is the actual path followed by the aircraft
- **Dead reckoning** or DR is the process of calculating one's current position by using a previously determined position, or fix, and advancing that position based upon known or estimated speeds over elapsed time and course.

Conventional location techniques - VOR orientation

- Orientation is an essential skill
- VORs orientation has been used for
decades - Two NAVAIDs are enough to pinpoint the location in 2D since radials are known
- Requires an undisturbed line of sight
- Accuracy is within $\pm 1^\circ$
- No elevation information is provided
- Subject to terrain interference
- Requires
multiple VOR stations within the line of sight
- Limited in distance
- Time-consuming, high workload
- Attention is required to operate

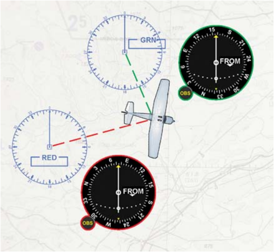
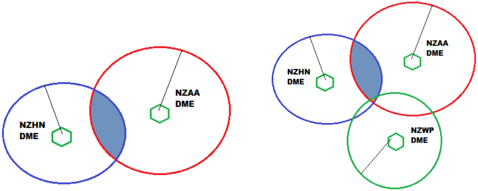


Figure 1: VOR location technique using 2 VOR stations

Conventional location techniques - DME orientation

- DME can be used for location
- 1 DME station gives a circle in which the aircraft is located
- 2 DME stations reduce position to 2 points where circles intersect
- 3 DME stations uniquely identify position – 2D fix
- Requires line of sight
- Involve only terrestrial stations – interference
- The accuracy of DME ground stations is ±185 m



(a) 2 stations (b) 3 stations

Figure 2: DME location

- GNSS includes a satellite constellation
- Positions

of the satellites are known and can be transmitted
- Satellites transmit UHF signals (line of sight!)
- Receivers can "see" multiple satellites
- Speed of signal is roughly uniform

(speed of light)
- Multiple

satellites are required to pinpoint the location

Figure 3: Satellite orbits

Satellite-based navigation cont'd

- Each satellite is sending out signals with the following content: I am satellite X, my position is Y and this information was sent at time Z
- Each satellite sends data about the position of other satellites. These orbit data (ephemeris and almanac data) are stored by the GPS receiver for later calculations
- Position is accrued using the process of trilateration (determining a distance from three points)
- At least three satellites are required to determine the position of the GPS receiver on the Earth's surface
- A 3D-position fix also gives the height above the earth's surface
- Each satellite has high-precision atomic clocks for time measurement

Figure 4: Satellite orbits

Each satellite sends
out a signal that includes its own position and the time. The receiver can calculate the time it took the signal to travel and multiply that by the speed of the signal (the speed of light) to compute the distance. That distance ("r" in the figure) defines a sphere. The receiver could be at any point on that sphere. On the diagram, it is more than just the black line; it is the entire outer shell of the sphere. (Remember: three dimensions.)

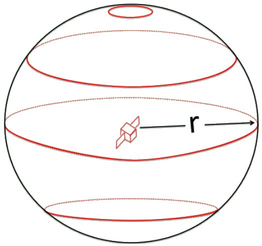


Figure 5: One satellite

Satellite-based navigation cont'd

With two satellites
you have an intersection of two spheres and the receiver could be in any position along those intersecting spheres. Once again, it is more than just the black lines in the diagram; your position could be at any point inside the three-dimensional shape described by the black lines.

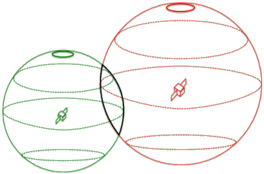


Figure 6: Two satellites

Satellite-based navigation cont'd

With
three satellites, you narrow the possible location down to one of two points (the two black points).

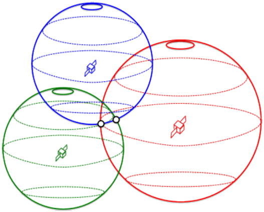


Figure 7: Three satellites

With one more satellite,
you have narrowed the universe of possible intersections to just one (the single black point).

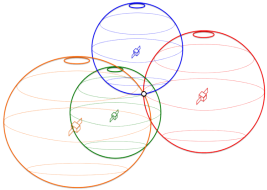


Figure 8: Four satellites

- Time
needed by a signal to travel from the first of two satellites to the receiver was determined to be 4s
- Second
satellite's transmission took 5s to be received
- The problem lies in
the determination of the exact runtime of signals
- Satellites use atomic clocks to measure time
- GPS receivers use a quartz clock – less accurate

Note: all times are exaggerations!

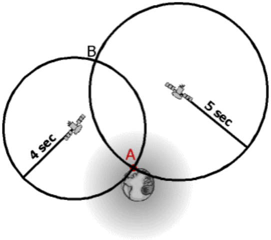


Figure 9: Satellite fix with 2 stations

Satellite-based navigation cont'd

- Time measurement error causes loss of precision
- Pseudoranges – satellite
distances without bias (synchronisation error)
- Depends on the accuracy of clock
- Clock
error of 1/100 sec gives position error of 3000 km
- To achieve 10 m accuracy
clock should be precise to 0.00000003 sec
- To overcome the clock accuracy problem....

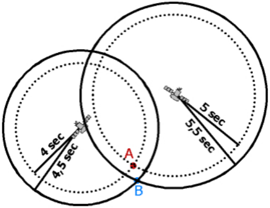


Figure 10: Satellite fix with 2 stations - pseudoranges

Satellite-based navigation cont'd

- GNSS uses 3 satellites
- Error in clock is visible immediately (point B)
- 2D fix requires 3 satellites
- 4th satellite

can be used to correct for the time inaccuracy
- The actual time span for signals from the satellite to the receiver lies in the range of 0.07 s
- Speed of light 300,000 km/s

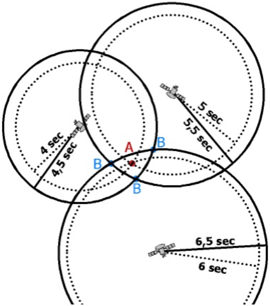


Figure 11: Satellite fix with 3 stations

Satellite-based navigation cont'd

Any errors from even a single satellite can throw off the estimated distance computations and, therefore, your estimated position.
The drawing makes light of a 5-second error, but at the speed of light, that would be 930,000 miles, exceeding the satellite's orbit. We must obviously be talking about very small time errors.

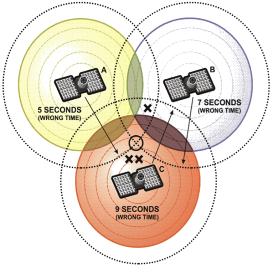


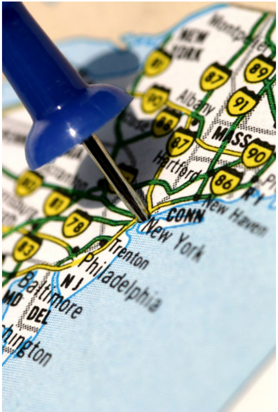
Figure 12: Position errors

Satellite-based navigation cont'd

- By constantly recalculating the position GNSS receiver can determine speed (referred to as ground speed) and the path over the ground (referred to as ground track)
- Another way to measure speed is to use the Doppler effect GNSS receiver requires unhindered reception of the satellite signals
- Satellites transmit the coarse locations of all other satellites (almanack data) and precise satellite coordinates (ephemeris data)
- Ephemeris contains satellite status – help identify misbehaving satellites and exclude them from the calculations
- GNSS data is controlled by the ruling agency
- Accuracy of the measurements can be altered by the controllers

Satellite-based navigation cont'd

- **Datum** - different calculations for determining longitude and latitude for a given location.
The most current geodetic datum used for GPS is the World Geodetic System of 1984 (WGS84)
- **Waypoint** - is a reference
point for a physical location on Earth. They are defined by a set of coordinates that typically include longitude, latitude and sometimes altitude



GPS

- GPS is an implementation of GNSS
- 24 satellites in orbits, 3 backup satellites
- Travel at 10,000 km/hr
- Powered by solar energy
- First satellite launched in 1978
- Full constellation of 24 achieved in 1994
- Each satellite lasts for 10 years
- GPS has 2 channels: L1 for
civilian use (coarse) and L2 for military (precise)

Figure 13: Satellite orbits

GPS cont'd

- GPS is controlled by the Department of Defence
- Signal quality and reliability
can be affected by natural and artificial hazards
- Various correction and augmenting
techniques used to improve the accuracy
- GPS was made public due to a
tragedy of 1983, when Korean Air Lines flight 007
entered Soviet airspace due to navigational error

Figure 14: Satellite orbits

GPS cont'd

- GPS satellites transmit two types
of code used for position identification—a "P" code, for "precise" navigation, and a "C/A" code
- P-code provides "Precise Positioning
Service" (PPS) that is only accessible to military receivers and requires a valid decryption key
- C/A code provides "Standard Positioning
Service (SPS), accessible to all civilian receivers

Figure 15: Satellite orbits

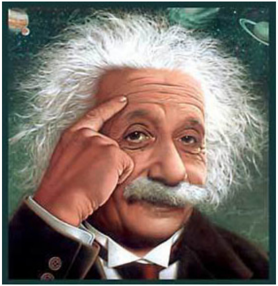
GPS cont'd

- TSO – technical standing order – defines and standardises various GPS functional requirements
- TSO-C129 are certified for non-WAAS receivers
- TSO-C146a utilises WAAS
- aircraft equipped with TSO-C129 GPS systems (non-WAAS) are only capable of utilising "lateral" GPS signal information TSO-C146a systems (WAAS) can descend down to what are referred to as LNAV/VNAV

Figure 16: Satellite orbits

GPS cont'd

- GPS is not just
for navigation – an exact time stamp can be used
- Relativistic effects
are taken into account (Einstein was correct!)
- Ground stations are
required to control the constellation of satellites
- Until 2000 Selective Availability
was used to cripple civilian band precision
- DoD name for GPS is NAVSTAR



Sources of GPS errors

Source	Uncorrected Error Level
Ionosphere	0-30 m
Troposphere/water vapors	0-30 m
Measurement noise	0-10 m
Ephemeris data	1-5 m
Clock drift	0-1.5 m
Multipath	0-1 m
Relativistic effects	0-15 m
Selective Availability	0-70 m

Table 1: GPS error budget

Sources of GPS errors cont'd

- Satellite signal
slows down passing through the atmosphere
- Ionospheric layers refract
the electromagnetic waves from the satellites,
resulting in an elongated runtime of the signals
- These errors are
mostly corrected by the receiver by calculations
- Military
GPS receivers use both frequencies (L1 and L2)
- influenced in different ways by the ionosphere
- The tropospheric effect is a further factor
elongating the runtime of electromagnetic waves by refraction due to
water vapour presence

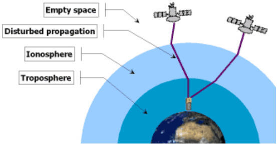


Figure 17: Atmospheric effects

Sources of GPS errors cont'd

- The multipath effect is caused by the reflection of satellite signals (radio waves) on objects
- This effect mainly appears in the neighbourhood of large buildings or other elevations
- The reflected signal takes more time to reach the receiver than the direct signal. The resulting error typically lies in the range of a few meters
- Usually can be mitigated
by moving the receiver away from the buildings

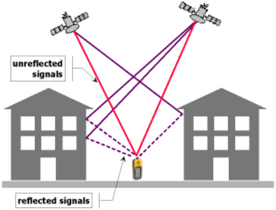


Figure 18: Multipath effects

Sources of GPS errors cont'd

- Clock inaccuracies and rounding errors
- Despite the synchronisation
of the receiver clock with the satellite
time during the position determination, the
remaining inaccuracy of the time still leads to an
error of about 2 m in the position determination
- Rounding and calculation errors
of the receiver sum up approximately to 1 m
- Time should be accurate to within
40 nanoseconds (1/40,000,000,000 of a second)

Figure 19: Receiver clock errors

Sources of GPS errors cont'd

- Although the satellites
are positioned in very precise orbits, slight shifts of the orbits are possible due to gravitation forces
- Sun
and moon have a weak influence on the orbits
- The orbit data
are controlled and corrected regularly and are sent to the receivers in the package of ephemeris data
- The influence on the
correctness of the position determination is rather low, the resulting error being not more than 2 m

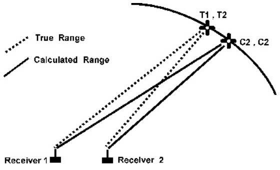


Figure 20: Orbital (ephemeris) errors

Sources of GPS errors cont'd

- Dilution of precision is an indicator of the quality of the geometry of the satellite constellation
- Computed position can vary depending on which satellites you use for the measurement
- Different satellite geometries can magnify or lessen the errors
- A greater angle between the satellites lowers the dilution of precision, and provides a better measurement
- A higher dilution of precision indicates poor satellite geometry, and an inferior measurement configuration

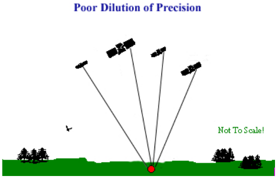


Figure 21: Dilution of precision

Sources of GPS errors cont'd

- Selective
availability is an artificial falsification of the time in the L1 signal transmitted by the satellite
- For civil GPS receivers, that
leads to a less accurate position determination (fluctuation of about 50 m during a few minutes)
- Additionally, the ephemeris
data are transmitted with lower accuracy
- The reasons for SA were safety concerns
- On May 2, 2000 5:05 am (MEZ)
the selective availability (SA) was turned off

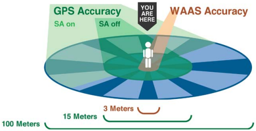


Figure 22: Intentional degradation of the signal – selective availability

- GPS
is one of the first systems, excluding high-energy accelerators, that is affected by relativity
- Time runs slower during very fast movements
- For satellites moving at speed, this
relativistic time dilation leads to an inaccuracy of time of approximately 7,2 microseconds per day
- The theory
of relativity also says that time moves more slowly when the field of gravitation is stronger
- Altogether,
relativistic effects errors can sum up to 15 meters!

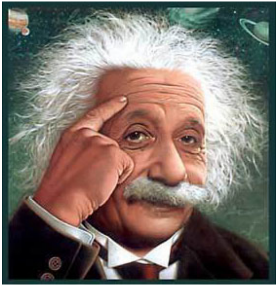


Figure 23: Relativistic effect

Augmentation technologies

- Augmentation systems shall provide additional accuracy and reliability for the GPS system
- The
main reason is to increase the safety for aviation
- The GPS
system is neither accurate nor reliable enough to be accepted as a sole means of navigation
- Can be based on ground stations, augmenting GPS position or additional statistical information
- Early augmentation – differential GPS
- Multiple systems: DGPS, WAAS, EGNOS, RAIM

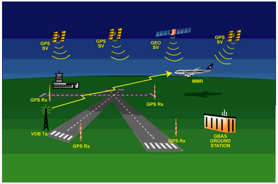


Figure 24: Augmentation technologies

Augmentation technologies - Differential GPS

- The idea behind all differential
positioning is to correct bias errors at one location with measured bias errors at a known position
- A reference receiver, or base station,
computes corrections for each satellite signal
- DGPS removes
common-mode errors, those errors common to both the reference and remote receivers
-
Differential position accuracies of 1-10 meters are possible with DGPS based on C/A code signals

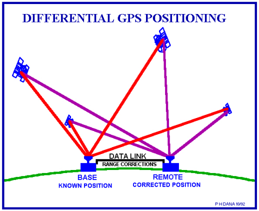


Figure 25: Differential GPS

Augmentation technologies - WAAS

- FAA is developing the WAAS
program for use in precision flight approaches
- Currently, GPS alone
does not meet the FAA's navigation requirements
for accuracy, integrity and availability
-WAAS corrects
for GPS signal errors caused by ionospheric
disturbances, timing and satellite orbit errors

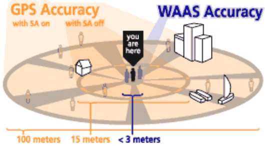
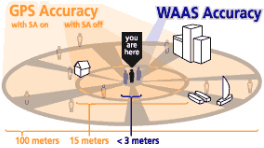


Figure 26: Wide Area Augmention System

Augmentation technologies - WAAS cont'd

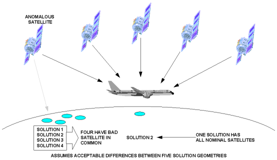
- Two master stations, located
on either coast, collect data from the reference stations and create a GPS correction message
- This correction accounts
for GPS satellite orbit and clock drift plus signal delays caused by the atmosphere and ionosphere
- The information
is compatible with the basic GPS signal structure



- The corrected differential message is then broadcast through 1 of 2 geostationary satellites, or satellites with a fixed position over the equator

Augmentation technologies - Receiver Autonomous Integrity Monitor (RAIM)

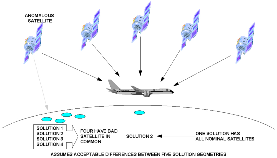
- RAIM is an
assessment of satellite(s) health (signals in/out of tolerance) which is performed within the receiver
- Depends solely on the GPS signals available without augmentation from another system
- The receiver computes the position solution using a set of four satellite signals; in this case, with five satellites being tracked, five solutions can be developed



- If there is an out-of-tolerance satellite, it is statistically predicted by comparing the solutions

Augmentation technologies - Receiver Autonomous Integrity Monitor (RAIM) cont'd

- NANU – Notice
Advisory to NAVSTAR Users (GPS Notam)
RAIM prediction report is used to determine coverage of GPS systems for a given flight path
- When en route RAIM warning for longer than 10 minutes requires ATS unit to be advised
- If RAIM warning appears during the approach, the approach shall not be commenced
- RAIM prediction should be obtained before departure



Augmentation technologies condensed

- Augmentation technologies provide improvements with regard to accuracy and integrity
- Require additional instrumentation: ground stations (WAAS), additional satellites in view (RAIM)
- Augmentation is required for the GPS receivers to be certified for GPS approaches
- RAIM prediction is to be obtained prior to departure
- Traditional receivers use RAIM only for FD (Fault Detection)
- Newer GPS receivers support FDE mode (Fault Detection and Exclusion) allowing the receiver to continue operating if fault is detected
- RAIM uses statistical methods to analyse and ensure the validity of pseudoranges
- GNSS NAVAIDs are in constant motion – very “liquid” environment

GPS nomenclature

- **RNP** – Required Navigation Performance
- **MNPS** – Minimum Navigation Performance Specification
- **VSM** – Vertical Separation Minimum
- **LRNS** – Long Range Navigation System
- **INS** – Inertial Navigation System
- **FMS** – Flight Management System
- **RVSM** – Reduced Vertical Separation Minimum
- **RNAV** – Area Navigation
- **RAIM** – Receiver Autonomous Integrity Monitor
- **FDE** – Fault Detection and Exclusion
- **APCH** – Approach
- **PBN** – Performance Based Navigation

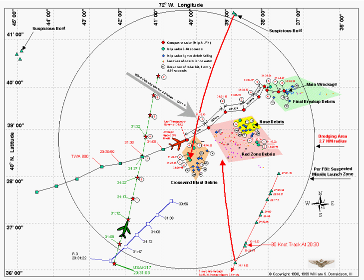
GPS nomenclature

- **ICAO** – International Civil Aviation Organisation
- **RTF** – Radiotelephony
- **HDG** – Heading
- **GS, GS** – groundspeed
- **TK** – Track
- **XTK** – Cross track
- **ATS** – Air traffic service
- **TSO** – Technical Standing Order
- **GNSS** – Global Navigation Satellite System
- **ABS-B** – Automatic Dependent Surveillance Broadcast
- **CFIT** – Controlled Flight Into Terrain
- **NDB** – Non-directional Beacon

GPS nomenclature

- **WAAS** – Wide Area Augmentation System
- **CDI** – Course Direction Indicator
- **STAR** – Standard Terminal Arrival Route
- **SID** – Standard Instrument Departure
- **OBS** – Omni Bearing Selector
- **WGS-84** – World Geodetic System
- **VOR** – VHF omni-range
- **TCAS** – Traffic Collision Avoidance System
- **LNAV** – Lateral Navigation
- **VNAV** – Vertical Navigation
- **FPL** – Flight Plan
- **ENT** – Enter

GPS in aviation



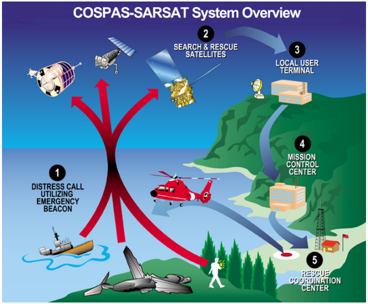
- With its accurate, continuous, and global capabilities, GPS offers seamless satellite navigation services that satisfy many of the requirements for aviation users

- Space-based position and navigation enables three-dimensional position determination for all phases of flight from departure, en route, and arrival, to airport surface navigation

GPS in aviation cont'd

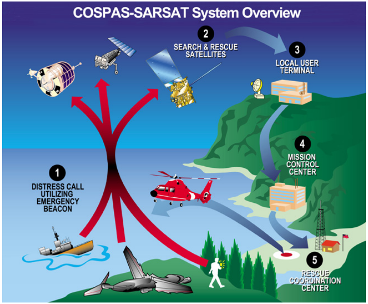
- Area Navigation (RNAV) allows aircraft to fly user-preferred routes from waypoint to waypoint, where waypoints do not depend on ground infrastructure
- GPS provides continuous, reliable, and accurate positioning information for all phases of flight on a global basis, freely available to all
- Potential decommissioning and reduction of expensive ground-based navigation facilities, systems, and services
- Increased safety for surface movement operations made possible by situational awareness
- Reduced aircraft delays due to increased capacity made possible through reduced separation minimums and more efficient air traffic management, particularly during inclement weather

GPS in aviation - critical situations



- One of the important GPS usages is to provide quick and reliable positioning information in case of emergency
- Use of GPS has become almost commonplace throughout the SAR operators
- GPS allows geographical information systems to be brought into the picture
- Increased spatial awareness provides the shortest response time

GPS in aviation - critical situations cont'd



- Recent statistics indicate that more than half of the pilots involved in mishaps did not file a flight plan before the accident flight
- With no positional information SAR process is heavily challenged
- GPS-equipped ELTs provide automatic position supply from the user in distress
- GPS may provide constant tracking of an aircraft and forward it to an online service for flight following

GPS in aviation - VFR flight

- GPS navigation
has become a great asset to VFR pilots
- Provides increased navigation capability
and enhanced situational awareness
- Reduces operating costs
due to greater ease in flying direct routes
- VFR pilots can use inexpensive
GPS receivers with limited accuracy
- Terrain
awareness function is becoming more
and more popular in modern receivers

- There are no legal
requirements for using GPS in VFR flights
- Easier identification of airspaces
- Great if used as a supplementary tool
- Still requires
visual reference to features on the charts
- Easy to follow a waypoint
by using "Direct to" functionality
- Easy
to identify winds and required corrections
- Requires training to identify
pitfalls and drawbacks of the technology

Figure 27: PROBLEMS

- Perceived ease of navigation
may cause loss of basic navigation skills
- Increases workload associated with programming GPS units instead of simply tuning a frequency and following a radial
- If mis-programmed,
a GPS guidance can get you
very accurately to a very unexpected place
- Proper
operations require up-to-date database and timely software updates if necessary

GPS in aviation - VFR flight cont'd

Figure 28: PROBLEMS

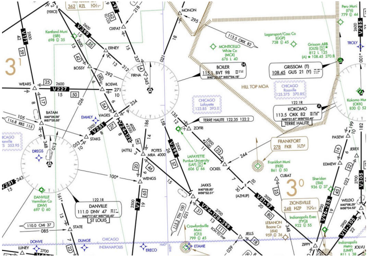
- Misunderstanding of technology
may lead to handling and positional
errors, for example, misunderstanding
DME and GPS distances difference
- A number of human factors
have been identified with relation to the
GPS use in VFR flight (discussed below)
- Perceived
ease of alternating the route may
be a cause of airspace violation or CFIT
- Excessive reliance on GPS may lead
to a loss of pilot visual navigation skills

GPS in aviation - VFR flight cont'd

Figure 29: Risk mitigation

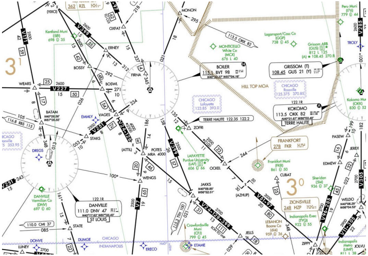
- Always plan
the flight before departure – fly the plan!
- Limit the
role of GPS to being a supplementary tool
- Always cross-check GPS data with
conventional VFR navigation methods
- Maintain lateral and vertical awareness
- Maintain terrain awareness
- Stay visual
- Maintain airspace awareness
- Maintain airspace tolerances
- Always check the validity
of input when programming a GPS unit

GPS in aviation - IFR flight

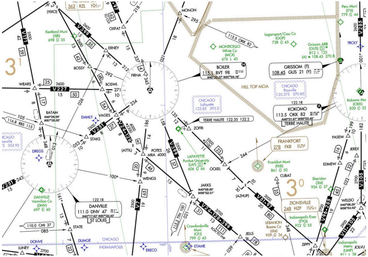


- Non-precision GPS approaches
have been flown for a while in NZ
- Almost all airports now
have GPS approaches published in AIP
-
CAA Rules Part 19, Subpart D “Transition rules” defines requirements for GPS use
- CAA
Rules Part 61, Subpart Q “Pilot Licenses and Ratings” defines requirements
for using GPS equipment in IFR flight
- Technical requirements published in TSOs

GPS in aviation - IFR flight cont'd



- Area navigation (RNAV)
- Required Navigation Performance (RNP)
- Position and event reporting
- Common Timebase
- Surface moving map
- Runway awareness and Advisory System (RAAS)
- Automatic Dependent Surveillance (FANS, ADS-B)



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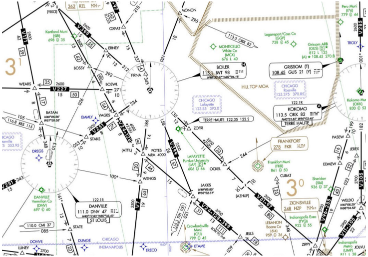
GPS in aviation - IFR flight cont'd

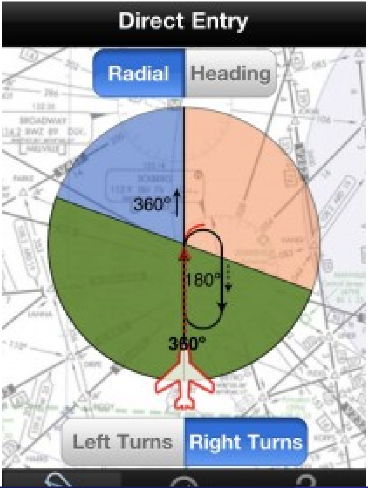


- Sole means of navigation is a navigation system that meets accuracy, integrity, continuity and availability requirements
- Primary means

of navigation is a navigation system that meets accuracy and integrity requirements
- Supplemental

means of navigation is a navigation system that must be used in conjunction with a sole means navigation system
- GPS equipment must be approved to

level 1 on form CAA 2129



- GPS equipment must be approved in accordance with TSO-C129
- GPS unit must be panel-mounted
- Aircraft must be equipped with an approved and operational alternate means of navigation
- An aircraft should not be operated under IFR using a sole means navigation system, which uses GPS sensors within the New Zealand Flight Information Region
- Ensure that the database is current with respect to the current published en-route and area data

GPS in aviation - IFR flight cont'd

- DME and GPS distances measured differently (slant vs direct)
- GPS derived distances can only relate to the reference points stored in the database
- In a position reports distance must be stated as a GPS distance relative to the specified reference point
- Under IFR using GPS equipment GPS derived distance must not be used if RAIM is unavailable for the proceeding 10 minutes

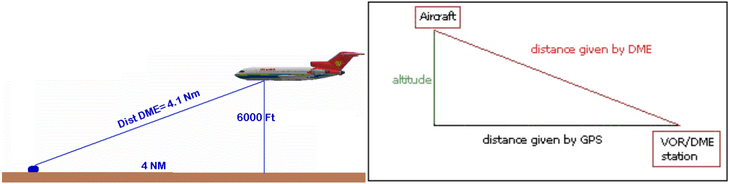
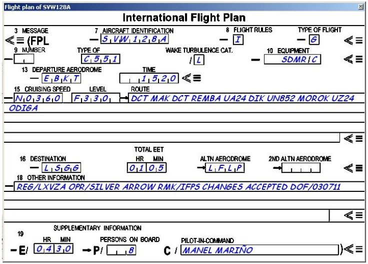


Figure 30: DME distancing


Flight plan of SVW128A

International Flight Plan

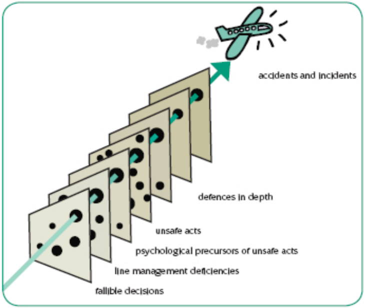
3 MESSAGE (FPL
7 AIRCRAFT IDENTIFICATION SVW128A
8 FLIGHT RULES I
TYPE OF FLIGHT G
9 NUMBER
TYPE OF C551
WAKE TURBULENCE CAT. / L
10 EQUIPMENT SDMR / C
13 DEPARTURE AERODROME EBKT
TIME 1520
15 CRUISING SPEED N0360
LEVEL F330
ROUTE DCT MAK DCT REMBA UA24 DIK UN852 MOROK UZ24 ODIGA
16 DESTINATION LSGG
TOTAL EET HR MIN 01 05
ALTN AERODROME LFLP
2ND ALTN AERODROME
18 OTHER INFORMATION REG/LXVZA OPR/SILVER ARROW RMK/IFPS CHANGES ACCEPTED DOF/030711
19 SUPPLEMENTARY INFORMATION
HR MIN E/ 0430
PERSONS ON BOARD P/ 8
PILOT-IN-COMMAND C / MANEL MARIÑO)

- An aircraft under
IFR can be operated using GPS equipment
only if the letter "G" is inserted in
the block item 10 on the ICAO plan form
- Letter "G" should not be entered
in item 10 unless the aircraft and the crew
comply with IFR rules and regulations
- When an alternate
is required a GPS flight plan must also
be created from the DST to the alternate

GPS in aviation - IFR flight cont'd

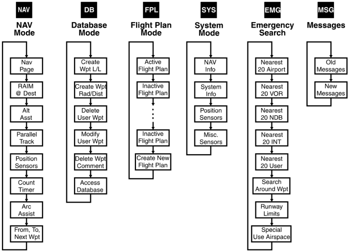
- A single-pilot IFR flight can be as safe as the pilot chooses it to be Autopilot coupled with GPS reduces workload dramatically
- GPS equipment, along with autopilot, greatly decreases the prevalent source of reported pilot deviations – altitude deviation
- Positional awareness during approach is significantly increased when GPS is in use

GPS in aviation - Human factors related to GPS use



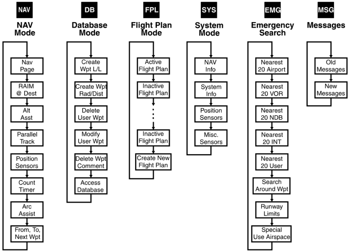
- GPS introduction
was probably the most important
event in the aviation industry since
the introduction of ATC radar in 1950s
- GPS
provides a new input stream for the pilots
- Information overload
can bring pilots to the state of despair
- Ergonomic
issues associated with GPS devices may
be an uninvited complication for the pilots

GPS in aviation - Human factors related to GPS use cont'd



- Typical GPS menu is organised around modes (NAV, DB, FPL, etc)
- Keystrike presents a problem of inadvertent input
- Load on memory – even a single parameter change requires extensive work with GPS knobs and keys
- Frequent input errors are experienced under high load and single-pilot IFR operations are full of high load times

GPS in aviation - Human factors related to GPS use cont'd



- Memory difficulty

is compounded by the multiplicity of functions on each of the knobs

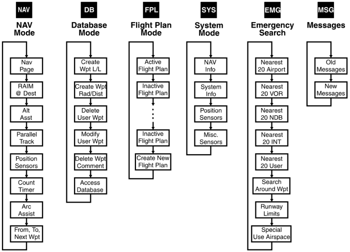
- When memory fails,

the pilot becomes literally unable to gain control over GPS receiver – information processing loop is greatly retarded

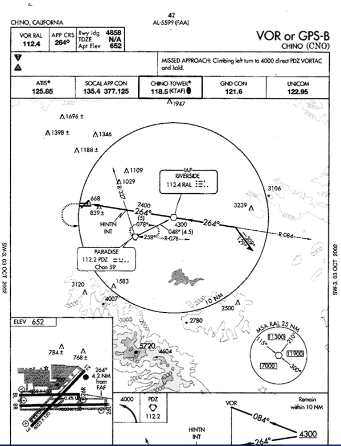
- Load on

memory increases with the non-intuitive logic of the GPS labelling and reporting

GPS in aviation - Human factors related to GPS use cont'd



- Over-reliance
on memory is another problem
- Recognition
may not be followed by information
retrieval in our brain – especially under
heavy load, fatigue or stress in general
- A number of incidents involved
pilots being so preoccupied with GPS
that they skipped other attention centres



- Database
errors, when the pilot selects invalid waypoints, present sa erious problem which is not easy to recognise unless care is taken to double-check every input
- In some cases, pilots chose to ignore some annunciator lights – sometimes related to the design of the actions
- Example: VOR
approach requires 5 steps, corresponding GPS approach may require a dozen

GPS in aviation - Human factors related to GPS use cont'd

- Factors associated with GPS displays have been the subject of extensive research
- In general, GPS incidents can be divided into 8 categories database error
— Distracted while operating GPS
— GPS malfunction
— Lack of knowledge
— Misinterpretation of data
— Mode error
— Over reliance on GPSP
— Programming error

GPS in aviation - Human factors related to GPS use cont'd

Over-reliance on GPS

- pilots took for granted the accuracy of the information
- pilot had committed mental resources to GPS, forgot about VOR or NDB backup.
- two pilots followed database fixes rather than ATC assigned way-points
- Expectation of alerts and/or moving maps to provide
- lost signal in remote area, got lost

Database Errors

- data cards had not been updated,
- did not contain the fix or facility,
- old frequencies on new cards or
- out of calibration

GPS in aviation - Human factors related to GPS use cont'd

Programming Errors

- input wrong latitude and longitude for intersections, or wrong fixes
- programming of units while airborne rather than set up flight plan on the ground.
- Caused altitude deviations and airspace violations while trying to reprogram, or gain situational awareness.
- Programming aircraft on approach and climbed into aircraft

Distracted While Operating GPS

- lost satellite, tried reprogramming GPS
- battery dead on the handheld GPS
- flew into the weather and tried to reprogram the computer to get out of the fog.
- engrossed in recovering from errors at the expense of piloting their aircraft.
- aircraft rolled forward into the runway as the pilot forgot to maintain brake pressure while distracted by programming GPS
- distracted on approach, hit trees
- engrossed in recovering from errors at the expense of piloting aircraft

GPS in aviation - Human factors related to GPS use cont'd

Malfunctions

Whether the events that occurred resulted from actual malfunctions or a rationale for being off course could not be determined. Installation error or when the GPS quit were cited as malfunctions

Lack of Knowledge

Problem areas in flight planning (airborne) programming instrument approaches, looking for airport, waypoint or VOR information; confusion with knob or button labelling, input errors.

Misinterpretation

- pilots did not understand the information on their moving maps or text display.
- Lost on final, perceived aircraft to be above, below or outside controlled airspace

Mode Error

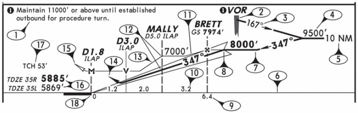
- selecting GPS mode rather than localizer for H.S.I. to execute the approach.
- forgetting to switch from GPS to VOR/Localizer
- Lost display during mode switching

GPS in aviation - Human factors related to GPS use cont'd

Training should enrich a pilot's understanding of their technology and have a positive effect on the pilot's sense-making. It should help reduce the ambiguity of operating a GPS.

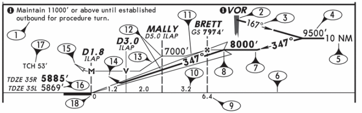
Training on avionics is a function of the knowledge of the instructor or the instructional method, the availability of user's manuals and the ability of the pilot or renter to train on the ground with the unit itself or with simulators.

IFR flight with GPS



- A pilot-in-command must be certified to carry out a flight under IFR rules
- A pilot-in-command
must be certified to carry out
the approaches using GPS receiver unless his/her logbook is properly certified for it
- GPS sensor-based sole means systems are not approved for use in New Zealand

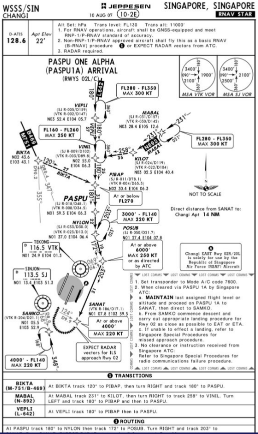
IFR flight with GPS cont'd



- If an alternate aerodrome is required, it must be ensured that:
— The alternate is served by a fully operational radio navaid with an instrument approach based on non-GPS navigation
— The aircraft is capable of using that navaid

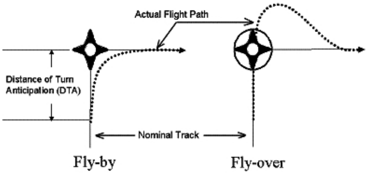
- Integrity and accuracy must be assured, for example, with WAAS and RAIM (primary means system)

IFR flight with GPS cont'd



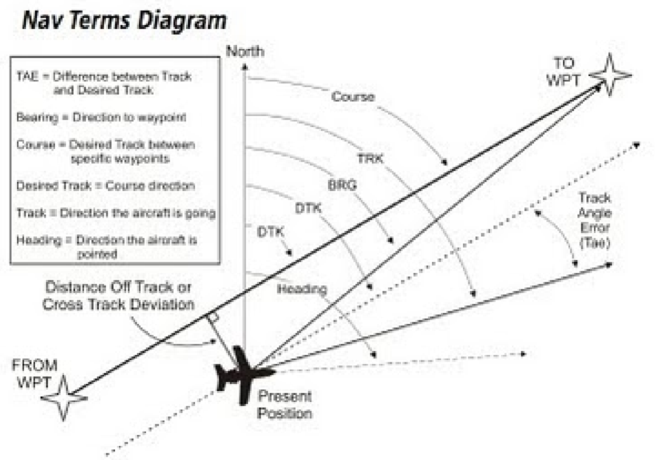
- RNAV approaches are based on waypoints, defining the course by the set of known GPS locations instead of by traditional ground-based navaids
- Waypoints can be fly-by type or fly-over type
- IAF – Initial Approach Fix
- IF – Intermediate Fix
- FAF – Final Approach Fix
- MAP – Missed Approach Point

IFR flight with GPS cont'd



- Fly-by waypoints used when aircraft should begin a turn to the next course prior to reaching the separating waypoint
- Fly-over
waypoints used when aircraft must fly over the waypoint prior to commencing the turn to the next waypoint in the sequence

IFR flight with GPS cont'd

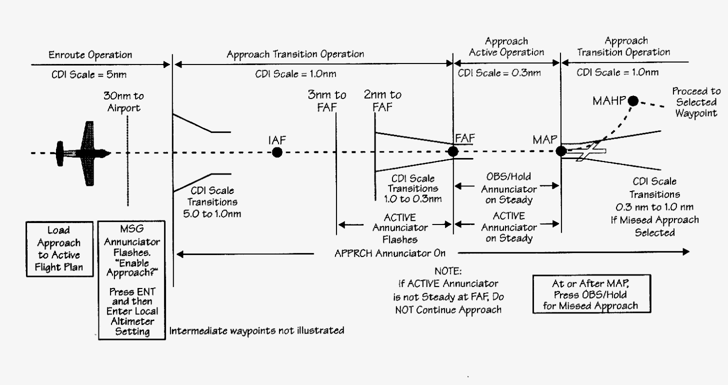


RNAV equipment displays cross-track deviation, not Angle off course

IFR flight with GPS cont'd

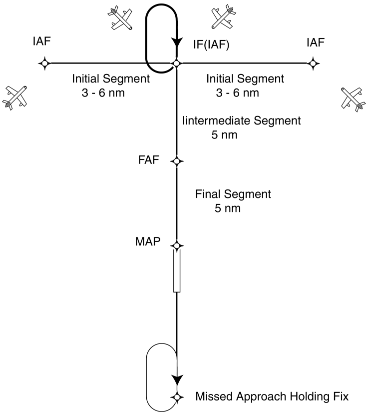
- Initial climb: From the end of the Takeoff subphase to the first prescribed power reduction, or until reaching 1,000 feet above runway elevation or the VFR pattern, whichever comes first
- En route: From completion of Initial Climb through cruise altitude and completion of controlled descent to the Initial Approach Fix (IAF)
- Approach: From the Initial Approach Fix (IAF) to the beginning of the landing flare
- Initial Approach: From the IAF to the Final Approach Fix (FAF)
- Final Approach: From the FAF to the beginning of the landing flare
- Missed Approach: 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 until the aircraft reaches the IAF for another approach

IFR flight with GPS cont'd



Sequencing of the waypoints in GPS is automated. If sequencing must be held/changed, OBS function is used.

IFR flight with GPS cont'd



- Terminal Arrival Area (TAA) procedure provides a transition method for the GPS-equipped aircrafts
- No procedure turns are needed
- The bases "T" design aligns the instrument approach procedure on the runway centreline
- MAP is at runway threshold
- Holding pattern at IF/FAF for pilots that elect to execute a procedure turn, for example, to meet descent gradient requirements GPS Standard Instrument Approach procedure always has FAF
- The FAF is used as a sensor to stop waypoint sequencing at FAF

- Minimum GPS approach has 4 waypoints: IAF-FAF-MAP-MAHP

Performance-based navigation

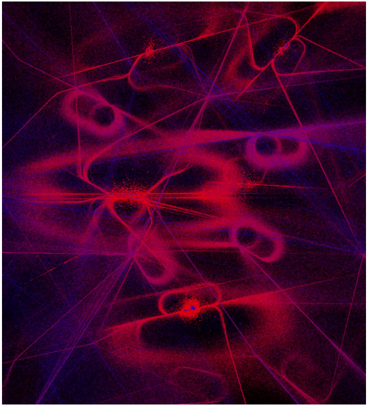


Figure 31: London zone tracks

Performance-based navigation (PBN) represents a shift from sensor-based to performance-based navigation. PBN specifies that aircraft RNP and RNAV systems performance requirements be defined in terms of accuracy, integrity, availability, continuity and functionality required for the proposed operations in the context of a particular airspace, when supported by the appropriate navigation infrastructure.

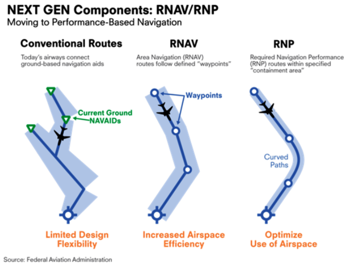
Performance-based navigation cont'd

PBN is based on the ability to assure reliable, repeatable and predictable flight paths for improved capacity and efficiency in planned operations.

The implementation of performance-based flight operations requires not only the functions traditionally provided by the RNAV system, but also may require specific functions to improve procedures, and airspace and air traffic operations.

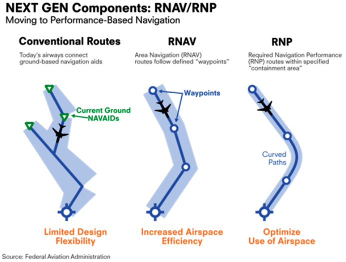
The system capabilities for established fixed radius paths, RNAV or RNP holding, and lateral offsets fall into this category.

Performance-based navigation cont'd



- Required
navigation performance (RNP) is a type of performance-based navigation (PBN) that allows an aircraft to fly a specific path between two 3D-defined points in space.
- RNAV
and RNP systems are fundamentally similar. The key difference between them is the requirement for on-board performance monitoring and alerting.

Performance-based navigation cont'd



- RNP also refers to the
level of performance required for a specific procedure or a specific block of airspace.
- An RNP of
10 means that a navigation system must be able to calculate its position to within a circle with a radius of 10 nautical miles.
- An RNP of 0.3 means the
aircraft navigation system must be able to calculate its position to within a circle with a radius of 3 tenths of a nautical mile.

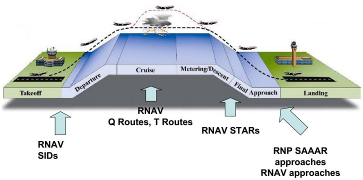
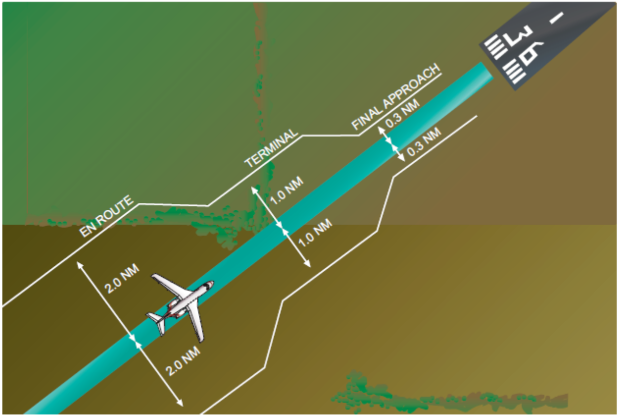
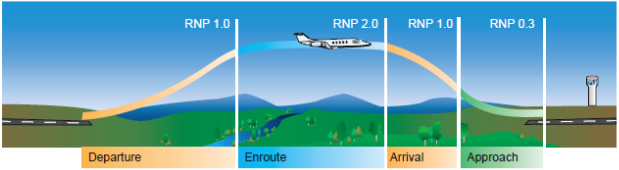


Figure 32: RNAV phases

- Some oceanic airspace has an RNP of 4 or 10. The level of RNP an aircraft is capable of determines the separation required between aircraft.
- RNP approaches with RNP values currently down to 0.1 allow aircraft to follow precise 3 dimensional curved flight paths through congested airspace, around noise sensitive areas, or through difficult terrain.

Performance-based navigation cont'd





Performance-based navigation cont'd

RNP APCH supports all leg types and path terminators used in standard RNAV, including TF and RF. RNP AR procedures support only two leg types:

- TF leg: Track to fix, a geodesic path between two fixes.
- RF leg: Radius to fix. This is a curved path supported by positive course guidance. An RF leg is defined by a radius, arc length and a fix. Not all RNP-capable FMS systems support RF legs.

RNP procedures were introduced in the PANS-OPS (ICAO Doc 8168), which became applicable in 1998

Performance-based navigation cont'd

The performance monitoring and alerting requirements for RNP 4, Basic-RNP 1 and RNP APCH have common terminology and application. Each of these specifications includes requirements for the following characteristics:

Accuracy: The accuracy requirement defines the 95% Total System Error (TSE) for those dimensions where an accuracy requirement is specified. The accuracy requirement is harmonised with the RNAV navigation specifications and is always equal to the accuracy value. A unique aspect of the RNP navigation specifications is that the accuracy is one of the performance characteristics that is monitored.

Performance monitoring: The aircraft, or aircraft-and-pilot combination, is required to monitor the TSE, and to provide an alert if the accuracy requirement is not met or if the probability that the TSE exceeds two-times the accuracy value is larger than $10-5$. To the extent operational procedures are used to satisfy this requirement, the crew procedure, equipment characteristics, and installation are evaluated for their effectiveness and equivalence.

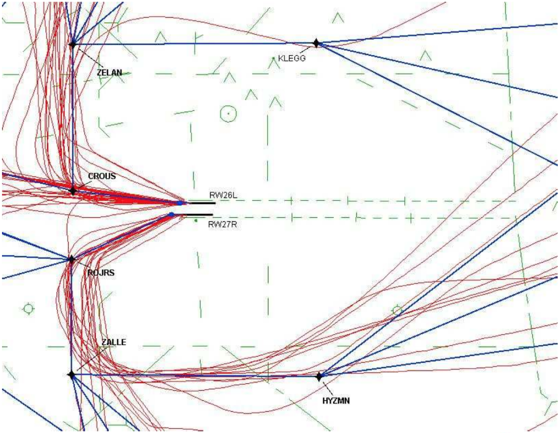
Performance-based navigation cont'd

Aircraft features: Failure of the aircraft equipment is considered within airworthiness regulations. Failures are categorised by the severity of the aircraft-level effect, and the system must be designed to reduce the likelihood of the failure or mitigate its effects. Both malfunction (equipment operating but not providing appropriate output) and loss of function (equipment ceases to function) are addressed. Dual system requirements are determined based on operational continuity (e.g. oceanic and remote operations). The requirements on aircraft failure characteristics are not unique to RNP navigation specifications.

Signal-in-space failures: Signal-in-space characteristics of navigation signals are the responsibility of the ANSP

Performance-based navigation cont'd

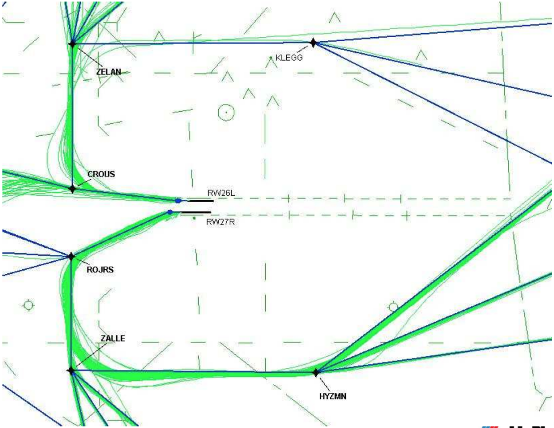
ATL Non RNAV Tracks



flightoperations
Flight Standards and Technology

UNITED
A STAR ALLIANCE MEMBER

ATL with RNAV Tracks



flightoperations
Flight Standards and Technology

UNITED
A STAR ALLIANCE MEMBER

ADS-B

ADS-B is radically new technology that is redefining the paradigm of COMMUNICATIONS - NAVIGATION - SURVEILLANCE in Air Traffic Management today. Already proven and certified as a viable low cost replacement for conventional radar, ADS-B allows pilots and air traffic controllers to "see" and control aircraft with more precision, and over a far larger percentage of the earth's surface, than has ever been possible before.

Automatic: It's always ON and requires no operator intervention
Dependent: It depends on an accurate GNSS signal for position data
Surveillance: It provides "Radar-like" surveillance services, much like RADAR
Broadcast: It continuously broadcasts aircraft position and other data to any aircraft, or ground station equipped to receive ADS-B

ADS-B cont'd

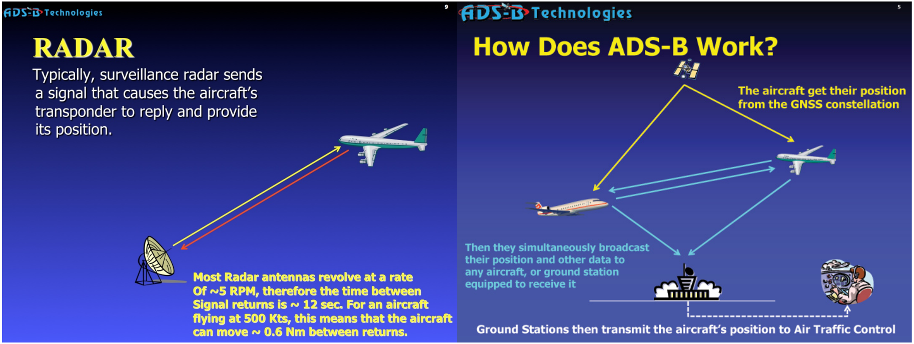


Figure 33: ADS-B schematics

Garmin 430


GARMIN
GNS 430
C
PWR VOL/PUSH SQ
V
VOL/PUSH ID
COM/VLOC
PUSH C/V
RNG
MENU
CLR
ENT
DEFAULT NAV
GPS
PUSH CRSR
COM
126.300
127.450
VLOC
117.30
109.10
APR
GIFFOR
VRB
VEP
FF11R
29L
04
X52
60
VERO
5.0
over zoom
GPS
MSG
NAV
CDI
OBS
MSG
FPL
PROC

Garmin 430

- The GNS 430 contains several receivers:
-
  - GPS
  - VOR
  - Localiser
  - Glideslope
- Permitted non-precision standalone GPS approaches(using GPS receiver), RNAV approaches (using GPS receiver), VOR approaches (using VOR receiver), ILS approaches (using Localizer/Glideslope receiver)
- Can fly DPs and STARs since they are in the database

Garmin 530

GARMIN
GNS 530
COM
136.975
118.000
VLOC
117.95
108.00
VOR
RAD
DIS
ENR
GPS
MSG
NAV
MAP CURSOR
086° 2250
N 27°36.20'
W081°05.27'
KCOF
KMLB
KLAL
FLORIDA
VRB
FORT P
LAKE ISTOKPOGA
LAKE OKEECHOBEE
LBV
RNG
MENU
CLR
ENT
DEFAULT NAV
PWR VOL
PUSH SQ
VOL
PUSH ID
COM/VLOC
PUSH C/V
CDI
OBS
MSG
FPL
VNAV
PROC
PUSH CRSR

Garmin 530

The GNS 530 represents the single biggest idea in integrated avionics in years.

Traditionally, it would take a host of components to provide the capabilities represented in this one sophisticated box.

It is a WAAS-upgradeable IFR GPS, Com, VOR, LOC and glide-slope with colour moving map all rolled into one. A TSO'd VHF Com offers a choice of 25 kHz or 8.33 kHz spacing for 760- or 3040-channel configuration, respectively.

A huge Jeppesen database (that can be updated with a front-loading data card) contains all airports, VORs, NDBs, Intersections, FSS, Approach, DPs/STARs and SUA information.

Garmin G1000

Garmin G1000

The Garmin G1000 is an integrated flight instrument system manufactured by Garmin, typically composed of two display units, one serving as a primary flight display, and one as a multi-function display. It serves as a replacement for most conventional flight instruments and avionics.

The Garmin G1000 is more than just a GPS. It is a full-fledged avionics system incorporating GPS, radios, flight management, engine monitoring, traffic and terrain avoidance, autopilot, and weather reporting.