Exam questions: AE3-295-II

1. NAVIGATION SYSTEMS (30 points)

In this question we consider the DME radio beacon.

[a] What does the acronym DME stand for? (3 points)

Solution:

DME stand for Distance Measuring Equipment

[b] How does the DME system work? In your answer, include: (12 points)

1. A description of the ground equipment and the airborne equipment (if any),

Solution:

Ground equipments are ground transponders or beacons consist of Antenna, Receiver, transmitters.

Airborne equipment named as airborne interrogator.

2. the basic working principle of the DME,

Solution:

DME is based on the measurement of the time interval between a pulse transmitted by the aircraft airborne DME interrogator and the reception of that pulse sent back (after a fixed time delay of 50 μs) by a ground-based DME transponder. The airborne equipment computes the SLANT RANGE (line-of-sight distance) between the aircraft and the DME station.

3. the DME signal characteristics,

Solution:

The aircraft interrogator transmits pulses on one of 126 frequencies between 962 and 1213 MHz (UHF). A DME channel consists of two carrier wave frequencies, always 63 MHz apart. E.g., the interrogation uses a 1025 MHz carrier wave for the interrogation pulse train, then the responder uses a 962 MHz carrier wave for the return pulses. The pulses, using a cos2-shape, are amplitude modulated on the carrier wave, in pairs 12 μs apart. Each pulse lasts 3 μs (so about 3000 cycles of the carrier wave in a pulse).

4. the different modes in which the DME can work,

Solution:

The interrogator can be in two modes. In the **search mode** the interrogator has not yet received an 'answer' from the ground station, and sends about 140 pulse-pairs per second. It has to recognize its own replies and ignore the replies to the DME interrogators of other aircraft. In the **tracking mode** the interrogator has recognized its own replies and is converting the information to a slant range. It sends about 5 to 8 pulse-pairs a second.

5. the characteristics of the DME in terms of accuracy, capacity and autonomy.

Solution:

Typical DME accuracy is ±1/4NM +1.25%R, with R the range in NM.

So, at a range of 100 NM, the accuracy is ±1.5 NM.

The ground station responds to the interrogations of more than one aircraft (50 - 100 aircraft) which all send their interrogations at the same frequency (the frequency of the DME beacon).

The interrogator has to recognize its own replies from the received array of replies to all other aircraft using the DME station. For this purpose, the aircraft interrogator is made to interrogate with its own rhythm (or jitter), and then looks for replies with a constant time difference with respect to the interrogator transmission.

[c] What is the DME reading in an aircraft that is flying at a horizontal distance of 20.4 NM from a DME station, at an altitude of 31000 feet? (1 ft = 0.3048 m, 1 NM = 1852 m). (5 points)

[d] Explain in detail how the aircraft equipment can distinguish between replies of the DME station for other aircraft and the replies of the DME station to the owncraft. (10 points)

2. SURVEILLANCE SYSTEMS (30 points)

[a] What aircraft variables or states can be measured or obtained with the secondary surveillance radar (SSR)? (3 points)

Solution:

Aircraft heading, distance, identity code and pressure altitude.

[b] Describe the two modes (Mode A, Mode C) of an SSR. How many codes can be selected in Mode A? (7 points)

Solution:

- **SSR Mode A:** interrogation interval P1 and P3 equals 8μs.

Transponder replies with Aircraft Identification Code (ACID), defined by ATC and set by the pilot on the transponder cockpit interface

12 ‘bits’ : 2^{12} possibilities → 4096 ACID codes

- **SSR Mode C:** interrogation interval P1 and P3 equals 21μs.

Transponder replies the aircraft pressure altitude in steps of 100 ft (QNE), i.e. aircraft flight level (FL).

[c] Describe the interrogation/reply process of an SSR and an aircraft transponder. How does the transponder know what reply it should give? What do the interrogation signals look like? (10 points)

Solution:

Interrogation: Interrogations consist of three pulses, 0.8μs in duration, referred to as P1, P2 and P3. The timing between pulses P1 and P3 determines the mode (or question) of the interrogation, and thus what the nature of the reply should be. P2 is used in side-lobe suppression. Mode A uses a P1 to P3 spacing of 8.0μs, and is used to request the beacon code, which was assigned to the aircraft by the controller to identify it. Mode C uses a spacing of 21μs, and requests the aircraft's pressure altitude, provided by the altitude encoder.

Reply: Replies to interrogations consists of twelve data pulses uniformly spaced between two framing pulses. The reply is encoded by the presence or absence of a 0.45μs pulse in each slot. These are labeled as follows:

F1 C1 A1 C2 A2 C4 A4 B1 D1 B2 D2 B4 D4 F2 SPI

The F1 and F2 pulses are framing pulses, and are always transmitted by the aircraft transponder. They are used by the interrogator to identify legitimate replies. These are spaced 20.3μs apart.

The A4, A2, A1, B4, B2, B1, C4, C2, C1, D4, D2, D1 pulses constitute the "information" contained in the reply. These bits are used in different ways for each interrogation mode.

For mode A, each digit in the transponder code (A, B, C, or D) may be a number from zero to seven. These octal digits are transmitted as groups of three pulses each, the A slots reserved for the first digit, B for the second, and so on.

In a mode C reply, the altitude is encoded by a Gillham interface, Gillham Code, which uses gray code. The Gillham interface is capable of representing a wide range of altitudes, in 100-foot increments. The altitude transmitted is pressure altitude, and corrected for altimeter setting at the ATC facility. If no encoder is attached, the transponder may optionally transmit only framing pulses (most modern transponders do).
The X bit is currently only used for test targets. This bit was originally transmitted by BOMARC missiles that were used as air launched test targets. This bit may be used by drone aircraft.

[d] Describe the phenomenon of side-lobe interrogation. How is this problem solved for the SSR? (7 points)

Solution:

Every antenna, however, has a main lobe and several side-lobes. Now, the transponder cannot determine whether a received pulse is from the main lobe or from a side lobe, at least when the signal strength (which depends also on the distance between the transponder and the antenna) is about the same. In other words, the strength of the main lobe interrogation of far-away radar can well be the same as the strength of the side lobe interrogation of near-by radar.
This could lead to the transponder replying to the side-lobe interrogations of the near-by antenna → side-lobe interrogation.
To prevent this, P2 is sent with an additional omni-directional antenna with a magnitude larger than any of the antenna's side lobes:
P2 is smaller than P1 and P3 only in main lobes of P1 and P3. Hence, the transponder only replies to the main lobes, i.e. when P1 and P3 are 9 dB larger than P2.

[e] The SSRs can be upgraded with Mode S. What is Mode S and what primary virtue does it have with respect to the 'old' system? (3 points)

Solution:

Over-interrogation:

The aircraft transponder is interrogated by more than one SSR and gets saturated → replies are no longer valid.

Fruiting:

A particular SSR considers the answers of an aircraft transponder to another SSR as answers to its own interrogation → solved by introducing characteristic 'jitter' in SSR frequency (in a similar way as DME).

Garbling:

Two aircraft are at the same time and at approx. the same distance in the beam of an SSR, and they both reply to the same interrogation. The replies will be merged and no valid answer can be determined.

Solution: SSR Mode S ('S' from select(ive)):
SSR Mode S permits discrete addressing of aircraft: a unique 24-bit Mode S address is assigned to each aircraft so that aircraft can be unambiguously identified and addressed worldwide: $2^{24} \approx 17$ million.

3. FUTURE AIR TRAFFIC MANAGEMENT

[a] Describe the means of Communication (the 'C' in CNS) in the present Air Navigation System. In your answer, include a discussion on coverage and availability of the communication services. (10 points)

Solution:

The means of exchanging information between aircraft (crew, air-borne computers), ground stations (air traffic control, ground-based computers) and satellites.

"The objective of an aeronautical communication service is to ensure that telecommunication and radio aids necessary for the safety, regularity and efficiency of air navigation are continuously available"

- Radio-transceivers (R/T) for air-ground communication (voice):
  - VHF: The use of VHF is limited to line-of-sight operations – the 'radio-horizon'. (118-136 MHz) with at least 25 kHz between two frequencies yields only 720 available frequencies (recently reduced to 8.33 kHz, i.e., 2160 channels)
  - HF: Allows 'over-the-horizon' communications, although HF connections are vulnerable to atmospheric disturbances (sky wave).
- Communication between Air Traffic Services (ATS) units (flightplan): the Aeronautical Fixed Telecommunications Network (AFTN)(telex & telephony)
- ACARS (Aircraft Communications Addressing and Reporting System): ACARS is a digital data link system transmitted via VHF radio. It allows airline flight operations departments to communicate with the various aircraft in their fleet.

The VHF transmission system can be considered as e-mail for airplanes. Aircraft have their unique address (ARINC), and the e-mail traffic is routed via ARINC computers to the proper company. It relieves some of the routine voice communication (mostly at automatic intervals) between flight crew and airline.

• Departure/arrival reports
• Passenger loads
• Fuel data
• Engine performance data

Current systems are low bandwidth (low # bits/sec), expensive, and local.

[b] Describe how the available means of communication affect the manner in which nowadays the air traffic is controlled. (10 points)
Solution:

[c] Describe the future of Communication in the Future Air Navigation System. In your answer, include the roles of data-link and the ATN. (10 points)
Solution:
→ private line communications
→ digital air-ground and air-air data link

[d] Describe the means of Surveillance (the 'S' in CNS) in the present Air Navigation System. In your answer, include a discussion on coverage and accuracy of the surveillance services. (10 points)
Solution:
The determination of the position and velocity of a moving vehicle. The calculation is done outside the vehicle.
"for effective ATC to be possible, people or systems on the ground must know the position of aircraft on a continuous basis and be able to estimate their future position. The idea of keeping track of an aircraft's position is known as surveillance"
The resolution of a radar is defined as its ability to distinguish between objects that are very close in either range or bearing.
The pulse width determines the range resolution: the ability to distinguish between two or more objects on the same bearing, but at different ranges.

The antenna beam width determines the bearing resolution: the minimum angular separation at which two objects can be separated when at the same range.
Generally, primary radars transmit two pulses (PA and PB) after each other at a different frequency. This so-called frequency diversity increases the chances of detection because:
a. The reflection characteristics of aircraft depend on the pulse frequency,
b. The 'lobing' effects of both radar pulses are different.

[e] Describe how the available means of surveillance affect the manner in which nowadays the air traffic is controlled. (10 points)

[f] Describe the future of Surveillance in the Future Air Navigation System. In your answer, include the roles of SSR and ADS-B. (10 points)

4. NAVIGATION SYSTEMS (30 points)

[a] Two categories exist of navigation systems, namely Positioning systems and Dead Reckoning systems.

1. Give a definition of both categories, clearly indicating the main difference between them. Give one typical example of a navigation system for each category. (5 points) (5 points)

Solution:

Dead Reckoning systems: derive the state vector from a continuous series of measurements relative to an initial position.
· 'Classical DR': air data, magnetic heading and wind velocities
· Inertial Navigation Systems: accelerations and angular rates are measured and integrated.
Dead Reckoning systems must be re-initialized as errors accumulate in time.

Positioning systems: measures the state vector without regard to the path travelled by the vehicle in the past.
· Celestial navigation, on the basis of stars;
· Mapping navigation systems, using observed (visual) images of the Earth's surface;
· Radio navigation systems, on the basis of radio signals transmitted by ground beacons, satellites or (other) aircraft.

2. Discuss the advantages and disadvantages of dead reckoning navigation systems with respect to positioning navigation systems. (5 points)

Solution:

Advantages of Inertial Navigation Systems:
· Continuous availability of position, velocity and attitude information
· Self-contained: IN is based on measurements on-board
· Autonomous: IN does not depend on other systems
· Passive: IN does not radiate, it is not 'jammable'
· High accuracy

Disadvantages:
· Expensive ($50,000 - $150,000)
· DR system, so position and velocity information degrades in time
· Initial alignment is necessary
· Accuracy depends somewhat on the vehicle maneuvers

[b] Consider the VOR radio beacon, a so-called Θ-system.

1. What does the acronym VOR stand for? Why is it called a Θ-system? (5 points)

Solution:

VOR, short for VHF Omni-directional Radio Range, is a type of radio navigation system for aircraft.

It is also called as ϴ-system because it uses two ϴ-system to detect the position of an airplane.

2. To which of the two navigation system categories does the VOR beacon belong? (5 po)

Solution:

- ϴ-system
- row--ϴ-system

3. What are the characteristics of the VOR beacon in terms of capacity and autonomy? (5 points)

Solution:

[c] Consider Figure 1 showing two VOR beacons from above.

• Any navigation system is subject to making errors, and in this respect the GDOP measure is an important benchmark. What does the acronym GDOP stand for? And what does it mean? (5 points)

Solution:

GDOP is stands for Geometric Dilution of Precision.

GDOP relates ranging errors (line-of-sight) to the dispersion in measured position.

• Explain the concept of GDOP using Figure 1. In your answer, place the aircraft receiver at positions A, B and C and describe if and how the GDOP changes. (10 points)

5. FLIGHT MANAGEMENT SYSTEM (45 points)

1. Before the introduction of Flight Management Systems in the cockpit so called Aircraft Operating Manuals (AOMs) were used. What is an AOM? And what were they used for? (10 points)

Solution:

The AOM contains and describes all aircraft performance-related data needed for the operation of the aircraft. E.g. fuel consumption as a function of cruise altitude, type of cruise (long range, high speed, economy), trip distance (see example slide). The flight crew must interpolate data from the AOM tables to find the 'optimal' settings (e.g. engines) for the appropriate flight condition.

The 'optimality' of a combination of a certain cruise condition and engine setting depends not only on flight conditions, but also on external factors independent of the aircraft (e.g. fuel prices at airports, salary of crew). These external factors are not included in the AOM.

Result: the optimization of flight management is difficult with the AOM only and it can also lead to high pilot workload. There is a need for a system that manages aircraft performance (optimal use) and that provides guidance along the optimal route.

2. Describe the main factors which have led to the development and introduction of the Flight Management System. (10 points)

Solution:

A number of technical and non-technical factors have led to the introduction of Flight Management Systems.

Non-technical drivers

· Quantifiable economic benefits: optimize flight performance to minimize cost.

· Pilot workload.

· Growth of air traffic, resulting in more stringent air traffic control-related requirements on 3-D and, if possible, 4-D navigation.

Technical drivers

· Availability of accurate navigation sources, e.g., GPS, INS.

· Availability and affordability of very powerful and reliable computer systems, capable of storing and manipulating very large amounts of data.

· Ability to connect the various subsystems, providing data to the FMS by an efficient digital data bus system.

3. Make a sketch of the main components of an FMS and, using this sketch, describes the function(s) of these components. How is the information from the FMS presented to the pilots? And through what device can pilots interact with the FMS? (10 points)

Solution:

See slides

4. What are the three main tasks of an FMS? Explain these tasks in detail. (15 points)

Solution: tasks are given below:

1. ***Flight Planning:***

The FMS provides a computerized flight planning aid to the pilot (through the Control/Display Unit) and enables major revisions of the flight plan to be made in flight.
The FMS contains a data base (in the FDSU) of:

· navaids (VOR, DME, etc.) : identification, position, frequency, etc.

· waypoints : ID (are usually beacons).

· airways : ID, waypoints, magnetic course.

· airports : ID, lon/lat/alt, elevation, alternatives.

· runways : ID, length, elevation, lon/lat/alt.

· airport procedures : SID, STAR, ILS, descent profiles.

· company routes : original airport & destination airport, route number, type, cost index, etc.

The navigation database is updated every 28 days (as required by ICAO).

2. ***Navigation and Guidance:***

The FMS combines the data from all the navigation sources (INS, GPS, navaids) to derive the best estimate of the aircraft position and velocity sensor fusion. The FMS selects and automatically tunes the navaids specified in the flight plan and carries out the navigation computations. The FMS computes the aircraft ground speed, its track, the wind direction and the wind velocity.
The FMS provides both lateral (LNAV) and vertical (VNAV) guidance to the automatic Flight Control Computer (FCC) – the Auto Pilot – to control the aircraft along the planned trajectory. If possible (and allowed), the FMS applies random navigation (RNAV) guidance.
The FMS provides guidance signals to the automatic Thrust Control Computer (TCC) – the Auto Throttle.

3. ***Optimization and Performance prediction:***

The FMS selects the speed, altitude and engine power settings during all phases of flight, taking into account the flight plan, the prevailing conditions and the optimization of the operation of the aircraft.
For optimization of the flight plan, the FMS integrates knowledge about:

· Aircraft type and weight, fuel weight;

· Engine type and performance characteristics;

· Aircraft center-of-gravity position;

· Wind, air temperature;

· Flight level and flight plan constraints;

· Aircraft status, e.g. airspeed, height, Mach number;

· Company route index.

This yields an optimal time-referenced flight plan.
The FMS predicts performance in terms of:
· time, altitude, fuel, wind, temperature at each waypoint of the flight plan;
· ‘engine out’ performance;
· climb and descent computations;
· altitude and time markers;
· 3-D and 4-D performance;
· airrival times (for air traffic control/management).
Modern FMS allow precise 4-D navigation (in seconds accurate).