Podcast 38 – Flight Management, Navigation

Hello everyone and welcome again to the 737 Talk podcast where this episode we will be getting technical again with a look at the 737NG Flight management, navigation systems.

Before that though we'd like to wish all our listeners a very merry Christmas as we look to the end of what has been a very difficult year in our industry. The next episode is scheduled for 2022 so we'd like to wish you all a prosperous new year and if you've been out of them, a return to the skies in 2022. We've been writing these podcasts for a year now and we're not done yet! We're looking forward to bringing you many more in 2022 including interviews, competitions and more tech and procedural stuff. As well as that Ian and I have been busy creating more content over on b737training.org which we will continue to do throughout 2022, so as our Christmas present to you we'll be offering 20% off the site between now and January 3rd using the code CHRISTMAS2021, making the cost far less than that of your average turkey dinner! That's all upper case and no spaces, enjoy! Thanks again for spending your time with us and we look forward to bringing you even more content.

Back to today's subject. Our Nav systems include the FMS, GPS, ADIRS, the radio navigation systems such as ADF, DME, ILS, marker beacons and VOR, as well as the transponder and weather radar. Some fits may also include the head up display or HUD but most airlines will forgo this extra expense for 737 line flying.

The FMS consists of numerous components. These are the flight management computer system, the autopilot/flight director system, the autothrottle, the inertial reference systems and the global positioning system. All these components can be used as independent systems, or in various combinations. The overall term FMS refers to the ability we have of joining these independent systems in an integrated way to provide continuous navigation, guidance and performance management.

The FMCs, or flight management computers, are the heart of the flight management system. We have two of these located in the electronic equipment compartment and they perform navigational and performance computations and provide control and guidance commands.

To access our FMCs we each have our CDU's, or control display units. These are also used for ACARS and maintenance functions. Both FMCs are continuously in sync and compare data, with the Left CDU normally the primary which will process all CDU inputs, select nav aids and transmit initial position for our ADIRU alignment as well as ensuring synchronisation between FMCs and providing the inputs to the AP and AT systems.

As well as the CDUs our primary flight deck controls are the AFDS MCP and two electronic flight instrument system, or EFIS, control panels. Our primary displays are the display side of the CDU, our outboard and inboard display units and the upper display unit.

The FMC uses crew entered flight plan information, airplane systems data, and data from the FMC nav and performance databases to calculate present position, and pitch, roll, and thrust commands required to fly the optimum flight profile.

The selected, or primary, FMC then sends these commands to the AT, AP and FD with map and route information sent to the onside respective pilots nav displays. We then use our EFIS panels to select which information we would like to see. Our MCP is used to select the AT, AP and FD operating modes with LNAV/VNAV required to fly the FMC optimum profile.

The FMC and CDU are used for enroute and terminal area navigation, RNP approaches and to supplement primary navigation means when conducting all types of instrument approaches.

Dual FMC installation is certified as a "sole source" navigation system allowing us to operate outside of radio navaid coverage. The second FMC serves as backup on failure of the primary.

When external positioning updating isn't available the FMC uses the IRS position as a reference. FMCs receive inertial data from their onside ADIRU. When the IRS is the only source of position reference the FMC applies an automatic correction to IRS position to determine most probable FMC position. This correction factor is developed by the FMC's monitoring the IRS performance when normal position updating is available to determine a typical IRS error value.

If we find ourselves flying under these conditions it is important for us to realise that navigation accuracy may well be less than required and we should monitor FMC navigation using the old fashioned radio aid tuning or radar information if available.

Ian just mentioned external positioning updating there but as usual assumed I knew what he was talking about instead of explaining himself. For once he was right so being the conscientious one I'll explain it. The primary source for vertical and lateral navigation are the ADIRUs but as they tend to wander a bit over time they need some help in remaining as accurate as we need them to be for our various RNP requirements.

Our clever FMCs update their position in priority order from GPS, twin or more DME, VOR + co-located DME, LOC + co-located DME, or Localiser. We do have the ability to inhibit this updating through the CDUs when required to do so by company procedures. We then get our ANP or actual navigation performance shown to us on the navigation display as well as POS SHIFT page 3/3. The aircraft is 95% certain our position lies within that ANP circle. Interestingly the Vertical Actual Navigation Performance or VNAP, which is shown on RNP PROGRESS page 4/4 represents the estimated maximum altitude error within 99.7% probability. Of course, this is only valid if we have the correct QNH set.

While we're talking FMCs let's have a quick look at how they're powered and what happens on loss of that power and also FMC failure.

The FMC requires continuous electrical power to operate. This power comes from the AC STBY BUS in the case of the left FMC and Transfer Bus 2 for the right. If power in interrupted for less than 10 seconds then LNAV and VNAV disengage, all entered data is retained and the FMC will resume normal operation when power is restored.

If on the ground and power is lost for more than 10 seconds then all entries must be done again. If power is lost for more than 10 seconds in flight then LNAV and VNAV disengage, entered data is retained and when power is restored the RTE LEGS page is displayed with the scratch pad message SELECT ACTIVE WPT/LEG shown, which you must then do before LNAV can be reengaged.

If an error or system failure results in reduced capability, then a scratch pad message may be generated by the FMC. If other system inputs to the FMC fail, then the affected CDU displays are blanked to prevent the appearance of any misleading data. To put an example here, if you lost the total fuel input then some performance data would blank. Any degradations that don't lead to a total loss are pointed out to us through either those scratch pad messages or the blanking of data.

If however, the right FMC were to fail we would get the FMC P/RST amber light on the autoflight status annunciator and the scratch pad message SINGLE FMC OPERATION on both CDUs. The boxed amber VTK, or vertical track, flag would appear on the right nav display and LNAV and VNAV would disengage if AP B was in use at the time reverting to CWS R/CWS P. AP A is available with LNAV/VNAV capability. After 25-30 seconds the right ND will display failure information but may be restored by placing the FMC source select switch to BOTH ON L through correct QRH use.

Should the Left FMC fail you will get the same autoflight status light but you will also get the FMC/CDU FAIL light on both CDUs and both CDU's will display failure modes. VTK will appear on the left ND and LNAV and VNAV will disengage but can be reengaged if AP B is in use or is selected. After 25-30 seconds the left ND will display failure information and only limited FMC operation may be continued using the right FMC but no changes may be made on the CDU. Again, you're into the FMC FAIL QRH which helps you to diagnose which failure you have and in this case will recommend to select that FMC source select switch to BOTH ON R thus restoring full operation capability in single FMC mode should the Left not be restored after the 1 minute waiting time.

The FMC FAIL QRH is one of the few with an Objective statement which reads "To restore dual FMC operation, configure for single FMC operation or resume conventional navigation". You can probably guess what's coming next then. Yep, Dual FMC Failure. In this scenario we will get that autoflight status annunciator light, the FMC/CDU FAIL light on both CDUs and both CDUs will display failure modes. VTK will appear on both NDs and LNAV VNAV will disengage. After 25-30 seconds both NDs will display failure information.

Referencing the QRH you are now to revert to conventional navigation and use supplementary procedures to set N1 and airspeed bugs.

Before moving on for a quick look at the GPS system we'll just quickly touch on the FMC approach logic.

The FMC transitions to "on approach" when we are within 2NM of the first approach waypoint, including transitions and procedure turns, OR, 2,000ft above airport elevation, whichever occurs first. This allows us to fly approaches using LNAV/VNAV modes as VNAV path will remain engaged even with speed intervene once flaps are selected.

When the FMC is "on approach" we get

- an additional UNABLE REQD NAV PERF-RNP message displayed on the ND
- VNAV will continue a descent when MCP altitude is set at least 300ft above current altitude
- If we are more than 200ft below the path VNAV command V/S zero until intercept and
- If the MCP altitude is set more than 250ft above the current altitude, VNAV remains in VNAV PATH

For an approach without a runway waypoint on the RTE LEGS page, the VNAV path is calculated to the MDA or a calculated altitude at the missed approach point. It remains our responsibility not to fly below MDA without adequate visual references.
To exit "on approach" we can press TOGA, land, the waypoint cycles to the first waypoint of the missed approach or we execute a direct to a waypoint in the missed approach.

Right, I need a rest after that so over to Mark for a review of the GPS system.

GPS updating has allowed us to fly much more accurately and led to introduction of RNAV followed now by RNP allowing us to now fly RNP-AR approaches into what were the more difficult destinations to get into previously.

The 737 has two GPS receivers we call the left and the right which automatically supply accurate position information to the FMC and other aircraft systems including the EGPWS and aircraft clock. The GPS antennas relay signals to the Multi-Mode Receivers, or MMRs, with the left GPS module in MMR1 and the right in MMR2. We can see the GPS position on POS REF page 2/3 and we can also see that position relative to the FMC position on POS SHIFT page 3/3. The NAV STATUS page 1 of 2 will show us which GPS is currently in use by the FMC for position calculation.

If you select the POS switch on the EFIS control panel the ND shows the left and right GPS symbols which will be identical and show as a single symbol when both receivers calculate the same position. System failure annunciates by an amber GPS light on the aft overhead IRS display panel. This light illuminates automatically when both GPS systems fail or on recall with a single GPS failure. It's then time to see what sort of approach you're expecting and whether you can carry it out. We cover RAIM and GPS satellite requirements in episode 23 PBN if you want a refresher of those.

If GPS data becomes unavailable the FMC position will be determined by radio or inertial IRS updating, more of which in a minute. You also have the ability to deselect the GPS on the NAV OPTIONS page 2/2 with a reason for this being if the selected approach is not based on WGS-84. You may get the scratch pad message GPS-L INVALID and GPS-R INVALID in areas where GPS jamming takes place, I know we do quite often when operating to Cyprus. In this case you should be aware of the supplementary procedure titled "FMC Navigation Check".

Thanks Mark. We'll now move on to our inertial system. This system computes position, ground speed and attitude data for the DUs, FMS and autoflight system to name a few. The main components include the ADIRUs or Air Data Inertial Reference Units, an inertial system display unit, ISDU, the IRS mode select unit, MSU, and an IRS transfer switch. The ADIRUs provide inertial position and track data to the FMC, and attitude, altitude, and airspeed to the CDS or Common Display System. Each ADIRU has an IRS and an Air data section. Here we'll focus on the IRS side, we'll save the Air Data side for a future episode.

We have two independent IRS systems, located in the E and E bay, with each IRS having three sets of laser gyros and accelerometers. They are our sole source of attitude and heading information, except of course for the standby attitude indicator and the standby magnetic compass.

In the normal navigation mode, we get attitude, true and magnetic heading, acceleration, vertical speed, ground speed, track, present position, and wind data to the appropriate systems from our IRS showing its importance to us. IRS outputs are independent of external nav aids.

We have to align the IRS using present position before it can enter NAV mode. Future present position is then calculated from the initial position and distance flown. We normally enter our present position through the CDU but there is the option on the ISDU keyboard on the aft overhead too. We must be stationary during alignment which can very occasionally be a problem in strong gusty winds meaning some operators leave the IRS in NAV mode under these circumstances but please refer to your company procedures on that.

Normal alignment between 78°15N or S is initiated by rotating the the MSU switch from OFF to NAV. Here we then get a short power test, illuminating the ON DC light. When that light extinguishes we then see the ALIGN light and the alignment process begins. Here is where we enter present position cross checking the airfield charts. Alignment will take between 5 and 17 minutes depending on our latitude.

Stored in the IRS memory is magnetic variation between 82°N and south and so the data corresponding to present position are combined with the true heading to determine magnetic heading.

A VERIFY POSITION scratch pad message will occur if lat/long position is not within 4NM of the origin airport and the message ENTER IRS POSITON is shown if the entered lat/long does not pass the IRS internal comparison test. Both would hopefully be cleared once we reset the system with the correct position and save us some blushes.

The flashing ALIGN light tells us the position entered doesn't pass one of the two internal comparison tests leading us to check our input. If the entered position disagrees with the last stored position, the first internal test is failed. If we re-enter the same position, it will be accepted, and the alignment process will continue. The second internal test compares the entered latitude with the system-computed latitude and if two consecutive entries of the same position fail this test, the FAULT light illuminates.

Boeing gives the option of a fast align for transit or through-flight stops with brief ground times, please check your company procedures on its use. It allows a 30 second fast align by rotating the MSU switch to ALIGN, setting position in the CDU and then moving that switch to NAV. Please refer to the supplementary procedure when doing this for the guidance notes. This will also zero any ground speed error.

If we lose both AC and DC power then alignment will be lost, which will also happen if we move the MSU switch out of the NAV position. If this happens in-flight navigation mode, including present position and groundspeed outputs, are lost for the remainder of the flight. We can however select ATT mode to relevel the system and provide an attitude reference. We need to maintain approximately 30 seconds of straight and level unaccelerated flight to complete releveling. Some attitude errors may then occur during acceleration but will slowly dissipate after acceleration stops.

Attitude mode also provides heading information, but we must manually enter the initial magnetic heading. We can do this by referencing the supplementary procedure "IRS Entries" which instructs us how to do this either through the CDU or the ISDU. Drift of up to 15° per hour can occur so we need to cross check with the standby compass and update the heading as required.

The IRS transfer switch on the overhead panel can be in Normal, Both on L or Both on R. In normal the captains PFD receives attitude and heading data from the left IRS with the FO PFD getting them from the right. If changed to both on L or R then attitude and heading data would be given to both PFDs from the selected IRS and an INST SWITCH amber message would appear in the lower right corner of both PFDs.

Our IRS can operate on either AC or DC power. The Left IRS normal power comes from the AC Standby Bus, with the Right ADIRU coming from AC Transfer Bus 2. Both are backed up by the DC switched Hot Battery Bus hence the ON DC light. The ground-call horn in the nose-wheel well will also sound on the ground to alert maintenance personal the IRS is on battery power. Back up DC power to the right IRS is automatically terminated if AC power is not restored within 5 minutes.

When we turn OFF the IRS it remains powered for 30 seconds with the ALIGN light illuminated until the system is completely shut down.

We'll finish up with a review of our radio navigation systems, transponder, and weather radar. We may come back to the subject again as there is such a lot of information here but we hope this is helping as a good refresher for you.

Rad Nav wise we may have either one or two ADFs, two frequency scanning DME's, Two ILS receivers, marker beacon indications and two VOR receivers.

We'll cover some salient points to these. ADF bearing pointers on the DUs will disappear if heading or track information is lost or invalid. DME wise, the FMC will autotune them as necessary for position updates with the identifiers of those being used shown on NAV STATUS page 1/2. We can inhibit specific DME station tuning on NAV OPTIONS page 2/2.

For DME to be displayed on the CDS we must manually tune it on the VHF nav control panel and put the respective EFIS VOR/ADF switch in the VOR position. DME distance is auto displayed on the CDS when the ILS receivers are tuned to a collocated DME and localiser facility.

ILS LOC and GS can be displayed on the standby attitude indicator and when in APP mode the FCCs send signal to select the localiser antenna in the radome.

Nav aid identification wise we can of course listen to the morse code identifier, but this is automatically converted to alpha characters for us on the PFD and ND. Should these be incorrect or the tuned frequency remains shown it is then up to us to listen to the ident for verification.

Two transponders are installed and controlled through a single control panel on the centre pedestal. Altitude reporting capability is provided but remember if we have unreliable flight deck altitude indications this is what is being transmitted to ATC. Transmissions to ATC are automatically enabled when the air/ground system indicates airborne.

Depending on the fit the transponder may also transmit flight number, airspeed or groundspeed, magnetic heading, altitude, GPS position and more! At airports with ground radar ATC can monitor our ground position when the transponder is active, which means not in OFF or STANDBY. TCAS modes though shouldn't be used on the ground. If we have Automatic Dependant Surveillance-Broadcast, or ADS-B fitted, data is downlinked, yep I had to look that up, it means to transmit data from a spacecraft, satellite, or aircraft, to ATC which may be used for airplane tracking. The left GPS provides data to Transponder 1 and the right GPS to Transponder 2. This is why when passing through an area of GPS jamming and you get those GPS INVALID messages you will also notice a fail light on the transponder.

On to the weather radar and a little bit of windshear to shake us up before we all get a well-deserved rest. Most of us are operating with the multi scan system so we'll concentrate on that now.

We get an ideal radar beam from our multi scan radar by it collating information from different radar scans into a total weather picture. Clever algorithms then eliminate ground clutter with the result being our ability to view all significant weather up to 320NM away. The system is powered by AC transfer bus 2.

In general we have an upper beam that detects intermediate range weather and a lower beam detecting short and long range by the automatic adjustment of the beams tilt and gain. This information is then stored in a temporary database and when the pilot selects a range the computer extracts the appropriate portions.

During automatic operation this far too clever machine uses variable gain based on atmospheric temperature profiles to compensate for variations in geographic location, time of day, and altitude to optimise returns in all flight phases.

As well as the standard red, amber and green we also have speckled red dots which indicate a threat such as hail, lightning or turbulence, and Magenta which indicates a horizontal flow of precipitation with velocities of 5 or more metres per second toward or away from the radar antenna indicating heavy turbulence.

Features of the multi scan radar include Path Attenuation Compensation, or PAC, Alert; Oceanic Weather Reflectivity Compensation and Overflight protection.

The PAC alert places an amber arc on the outermost range scale to warn us if intervening rainfall has created an attenuated area, or more simply put a radar shadow. It is activated during automatic radar operation and is operative whenever the radar is being operated in CAL gain and the aircraft is within 80NM of a thunderstorm.

Oceanic Weather Reflectivity Compensation uses the aircraft nav inputs to identify oceanic regions and automatically adjust gain and tilt to account for the decreased reflectivity of oceanic storms. Thresholds are adjusted to give us a more accurate flight deck picture of the threat to the aircraft.

Finally, before our brief windshear system overview, Overflight protection. This was designed to prevent inadvertent penetration of high-altitude thunderstorms. At extended ranges the upper beam scans the wet, reflective portion of a storm in the same manner as a conventional weather radar. As we approach the storm and the cell falls below the upper beam, Multiscan utilizes 6000ft of lower beam information to keep the reflective part of the storm in view. Within approximately 15NM of the aircraft, Multiscan compares the stored digital image of the storm with the latest sweep and shows whichever return is greater. This protection is operational above 22,000ft MSL and explains why when we sometimes switch to conventional type radar we get a different picture to the Multiscan.

Right, a quick review of Windshear and then everybody's favourite tech quiz before we all take a well-deserved break. This one has been jammed full of information and may well take a couple of listens for it to sink in but we hope it's been useful for you.

Windshear warnings and cautions are enabled from the start of the take-off roll until 80kts. From 80kts to 400ft, only warnings are enable and from 400-1200ft we're back to warnings and cautions. On top of this all alerts are disabled from 100kts until 50ft AGL.

On descent, below 2300ft the weather scan switches from a 180° to a 120° scan indicating the windshear detection system is activated. The smaller scan allows faster updates and also allows weather and windshear events to show simultaneously for the entirety of an event.

Windshear detection is always activated below 2300ft for take-off and landing even if the radar is turned off and will activate in both manual and automatic radar operation. In the approach, warnings and cautions are enabled from 1200ft – 400ft with Warnings only from 400ft – 50ft. From 50ft to touchdown all new alerts are disabled.

A windshear warning will be generated whenever a detected shear event occurs within +/- 0.25NM of the aircraft longitudinal axis and within +/- 30° of the aircraft heading. When on the ground the warning comes for events within 3NM.

A CAUTION is generated whenever a shear is detected outside the warning region and within +/- 30 degrees of the aircraft heading and less than 3NM from the aircraft.

Now, it shearly must be time for… TALKS TECH TEN

Q1: During IRS alignment the right-hand window of the IRS Display unit will display minutes remaining until alignment with the display selector in which position?

Q2: Moving the IRS selector from OFF to NAV momentarily illuminates which light?

Q3: What latitudes does the IRS store magnetic variation data between?

Q4: With the loss of AC power in flight what happens to the IRSs?

Q5: What distance will the WX/TURB mode of the weather radar display detected turbulence within?

Q6: What happens to entered FMC data if power is lost for more than 10 seconds on the ground?

Q7: What does the FMC message INSUFFICIENT FUEL imply?

Q8: What is the FMC wind direction referenced to?

Q9: What does the DRAG REQUIRED message on the CDU indicate?

Q10: What information is available when operating the IRSs in ATT mode?

Thanks again for listening to us and Merry Christmas to you all from us. Why not treat yourself to a year's subscription over at B737training.org for far less than the price of a Christmas meal out for one! Please continue to join us next year where we hope to produce more useful content and continue the Talk with you for another 12 months. For those of you operating over Christmas, stay safe and we'll see you all soon.