Podcast 22 – Air Systems

Welcome to another 737 Talk where this week we are delving into another system, this time the 737NG Air system. We will take a look at the bleed air system, the air conditioning system and the airplane pressurisation system. There's a lot to look at so let's get going.

Yes, there's quite a lot to get through today so we'll jump straight in. Air for the bleed air systems can be provided by a number of sources. These are, the engines, APU or an external air source. After engine start it is normally our engines that do the supplying.

The systems that rely on this bleed air are air conditioning and pressurisation, Wing and engine anti ice, Engine starting, Hydraulic reservoir pressurisation, the nitrogen generator system if installed and water tank pressurisation. Our switches on the air-conditioning panel allow us to operate the engine and APU bleed air supply system.

Engine bleed air is obtained by the 5th and 9th stages of the compressor section as you may remember from our engine podcast. When that 5th stage lower pressure air is insufficient for system demand the high stage valve modulates open to maintain adequate pressure. During takeoff, climb and in most cruise conditions 5th stage pressure is adequate and the high stage valve remains closed. When the high stage valve is open there is a 5th stage check valve that prevents reverse bleed airflow.

The engine bleed air valve acts as a pressure regulator and shutoff valve or PRSOV if you're playing acronym bingo this week. The PRSOV is a butterfly type valve which controls the flow of bleed air to the system limiting pressure to 42psi and temperature to 232°C or 450°F. With our engine bleed air switch in on, the valve is DC activated and pressure operated. DC power comes from DC Bus 1 and 2 for bleed 1 and 2 respectively and from the switched hot battery bus for the APU bleed. The PRSOV will automatically reduce bleed airflow in response to high bleed air temperature.

The PRSOV will close when either, the fire swich is pulled, the engine bleed air switch is off, the Bleed Trip off light illuminates or when starting the engine. The bleed trip sensors illuminate that Bleed Trip Off light when engine bleed air temperature or pressure exceeds those predetermined limits.

Before the hot air enters the ducts, it is necessary for it to be cooled to avoid damage. Here is where the precooler and precooler control valve come in. The precooler is an air-to-air heat exchanger with the cooling air supplied by the fan air supply. The precooler control valve will control the amount of this cool air available to maintain system limits within 199°C to 229°C or 390°F to 440°F when downstream of the precooler.

If the precooler cannot cool the air sufficiently the PRSOV closes and the Bleed Trip Off light illuminates.

Each side of the bleed air manifold has its own Duct pressure transmitters which provide bleed air pressure indications to the respective pointers on the duct pressure indicator which itself is AC operated by transfer bus 2. A little tip here is to remember that "AC lies" which means that if power to the indicator fails, the needles will remain in that position giving you false information.

Differences between the L and R indications are considered normal as long as there is sufficient air for cabin pressurisation. Typically, these splits result from time differences on each side on the cross over between low and high stage. Duct pressure should not at any time exceed 60psi, during take-off, climb and cruise it should be greater than 18psi and above 10psi after top of decent.

The isolation valve isolates the left and right sides of the bleed air duct during normal operations and is powered by transfer bus 1. A cautionary note here is that if power is lost to transfer bus 1 the isolation valve is stuck in its last position.

When in Auto the isolation remains closed except when: Either or both pack valve switches are in off or either or both engine bleed air switches are in off. The valve position is not affected by the APU bleed air switch.

This APU bleed air valve permits APU bleed air to flow to the bleed air duct. The valve closes automatically on APU shutdown and is DC controlled and pressure operated.

With both the engine and APU bleed valves open and the engines at idle thrust there is a possibility of the APU bleed air backpressuring the 9th stage modulating and shut off valve. This would cause the 9th stage valve to close. The APU itself has a check valve to prevent reverse bleed air flow from the engine.

We'll throw in a couple of limitations for free here in that the APU can be started through the entire flight envelope although it is recommended to start below FL250 and the APU bleed system can provide bleed air only for one pack inflight up to 17,000ft or bleed + electrics to 10,000ft.

Thanks for those Mark, very good value at that rate. Let's move on to some of our light indications. The DUAL BLEED LIGHT illuminates whenever the APU bleed air valve is open, and the position of the engine bleed air switches and isolation valve would permit possible back pressure of the APU. Here we must limit thrust to Idle. We would expect to see this after engine start before we've positioned the isolation switch back to its auto position.

The BLEED TRIP OFF light illuminates whenever overtemperature 254°C or 490°F, or over pressure, 220psi, is sensed. The PRSOV automatically closes to protect the duct. This situation is most likely to occur after a no bleed take off. The selection of climb thrust before placing the bleeds back to on can help mitigate this. To reset the Trip off the conditions have to return within limits and the TRIP RESET switch needs to be pushed.

The Trip reset switch is also used to reset the system with a PACK light or Zone TEMP light after temperatures cool to below the limits.
The Wing Body Overheat light will illuminate if the bleed air duct starts leaking hot bleed air in the areas of the duct where sensors are located. AC power is needed for the system to

function and on illumination Wing Anti ice should not be used. A relatively complex QRH is associated and is worth a look through before perhaps encountering it for the first time.

We'll get back to more of those lights later but now we'll have a look at the air conditioning system. We get our air for this system by processing air from the engine bleeds, APU bleed or a ground source. Preconditioned ground air will enter the aircraft air conditioning system through the mix manifold.

Two air conditioning packs supply the main mix manifold with conditioned air for distribution to the cabin through left and right sidewall risers. The flight deck air comes from the left pack, upstream of the mix manifold.

Normally our left pack uses air from bleed no1 and our right from bleed no2 and a single pack in high flow is capable of maintaining pressurisation and acceptable temperatures up to maximum certified ceiling.

The APU is capable of two pack operation on the ground and single pack in flight with most ground carts capable of two pack operation on the ground too. Do not operate more than one pack from one engine.

The amount of air entering the pack is controlled by the flow control and shut off valve which is also controlled by our pack switch on the air conditioning panel. This valve will also automatically close in the event of a pack overheat. The air then heads into the pack whose main components are made up of the air cycle machine, heat exchangers and Ram air inlet.

Once the air has entered it takes one of two paths. The first is the cooling cycle flow where the air is cooled and the second is the bypass. The bypass air is regulated by the temperature control valve as it is added to the now cooled air to give the selected temperature we have chosen on our air conditioning panel.

The air taking the cooling cycle flow firsts enters the primary heat exchanger where it is cooled by ram air coming in through the ram air doors. On the ground, or in slow flight with the flaps not fully retracted the ram air inlet doors move to full open and the RAM AIR DOOR FULL OPEN light illuminates.

In front of the ram air door, we have a deflector door. This extends when electrically activated by the air-ground sensor to protect the ram air system from ingesting contaminants on the runway.

The cooled air is now sent to the ACM compressor or Air Cycle Machine compressor where the air is compressed, gaining heat, and then passed to the secondary heat exchanger, again utilising ram air for cooling. After this the air is further cooled through expansion by entering the ACM turbine which in turn drives the ACM compressor. It is after this that the two airflows meet up again mixing to give us that selected temperature.

Overheat protection is provided by sensors located in the cooling cycle and will illuminate the PACK light in an overheat condition.

Just to finish up on the packs themselves we need to mention the fact that when both pack switches are in Auto with both packs operating the packs provide normal airflow. If one pack was to subsequently fail for any reason the other automatically switches to high flow to maintain the necessary ventilation rate. This switching is inhibited on the ground, or in flight with the flaps extended, to ensure adequate engine power for single engine operation.

An APU high airflow rate is also available on the ground when the APU bleed switch is on and either or both pack switches are positioned on high. This is designed to give maximum airflow when the APU is the only source of bleed air.

Electronic controllers command the pack temperature control valve toward open or closed to satisfy pack discharge requirements as we've discussed. Also, to mention on this is the fact if one primary pack control fails, the affected pack is controlled by the standby pack control in the opposite controller.

A primary or standby pack controller failure causes the PACK, MASTER CAUTION and AIR COND system annunciator lights to illuminate on recall. If both fail, then these lights will illuminate automatically. The pack will continue to operate without control unless excessive temperatures cause a trip off.

We have three zones we're able to temperature control. The flight deck, the forward cabin and the aft cabin. Each temperature selector can set the zone temperature between 18°C or 65°F and 30°C or 85°F.

The packs produce a temperature that satisfies the zone that needs the most cooling and then trim air is introduced in the zone supply ducts. The quantity of trim air is regulated by individual trim air modulating valves.

In single pack operation with trim air on, the zone temperature is controlled in the same way. If, however, the trim air is OFF the pack attempts to produce a temperature to satisfy the average demands of all three zones.

If air in a zone supply duct overheats the associated amber ZONE TEMP light illuminates and the associated trim air modulating valve closes. Once the duct has sufficiently cooled the fault can be reset using the TRIP RESET switch.

Two zone temperature controllers manage pack and zone temperature. The left controller takes care of the aft cabin zone and provides backup control to the flight deck while the right controller controls the forward cabin and primary control to the flight deck.

Failure of the primary flight deck temperature control causes an automatic switch to the back up and will illuminate the CONT CAB amber ZONE TEMP light on recall. Failure of both controls will automatically illuminate the lights.
Failure of the forward or aft control will cause the associated trim modulating valve to close. The temperature selectors will operate normally but the settings of the two zones will be

averaged with the amber ZONE TEMP light again illuminating on recall for the associated zone control.

Any failures affecting the trim air supply cause the temperature control system to control both packs independently. If flight deck trim air is lost the left pack provides conditioned air to the flight deck at the selected temperature with the right pack providing the temperature for the passenger zone that requires the coolest air.

In the event that a passenger cabin zone trim air, or all trim air, is lost, the forward and aft zone temperature demands are averaged for the right pack.

If any individual zone is switched off the temperature selector setting will be ignored by the temperature control system.

If all our zone controls and primary pack controls fail the standby pack controls command the packs to produce air temperatures which will satisfy the average temperature demand of the two cabin zones. The trim air modulating valves will close, and the flight deck zone temperature selector will have no effect on the standby pack controls.

Finally on this section is a look at what happens if we put all our temperature selectors to OFF. In this case we end up with a fixed pack temperature. The left pack outputs 24°C or 75°F with the right pack outputting a cool 18°C or 65°F.

Before we have a run through of the pressurisation system, we're going to take a look at air distribution including a look at the recirc fans and equipment cooling. We'll start though at the pointy end which is of course our main concern for personal comfort.

From the left pack we receive our air through several risers ending in outlets at floor ceiling and foot level. There is a dual-purpose valve behind the rudder pedals providing air to not only stop our feet becoming ice blocks but to also defog the inside of the No1 windshields. These valves are controlled by knobs located on the captains and first officers' seats; sorry I mean panels.

The passenger cabin air supply distribution consists of the mix manifold, sidewall risers and an overhead distribution duct.

On to an often-misunderstood element of the air distribution system and that's the recirculation fans. Firstly, we have two main bus AC powered fans we call the left and right. The recirculation fan system reduces the air conditioning system pack load and the engine bleed air demand.

Air from the cabin and E&E bay is drawn to the forward cargo bay where it is filtered, the now famous HEPA filters live here, and recirculated to the mix manifold. When both fans are on approximately 50% of the air is recycled air.

Each recirculation fan operates only if the respective RECIRC FAN switch is selected to AUTO. In flight the L fan operates if both packs are operating unless either pack switch is in high. The

R fan operates operates in flight if both packs are operating unless both pack switches are in high.

On the ground the L fan operates unless both pack switches are in high whereas the R fan will operate even if both switches are in high.

Nice and easy to remember that! I'm sure equipment cooling is more straight forward. The equipment cooling system consists of a supply duct and an exhaust duct, told you. More detail? Ok, well the supply duct supplies cool air to the flight deck displays and the electronic equipment in the E&E bay. The exhaust duct then collects and discards warm air from the flight deck displays, the overhead and aft electronic panels, circuit breaker panels and the E&E bay equipment. Exhaust air is either vented overboard through the overboard vent via the exhaust valve or around the forward cargo compartment.

There are 4 fans in total powered by the AC system, a normal and an alternate for both the supply and exhaust fans.

The equipment cooling OFF light will illuminate if there is a loss of airflow through the system. Selecting the alternate fan should restore the airflow and extinguish the OFF light within approximately 5 seconds.

On some 737s in the event of a forward cargo fire warning the equipment cooling exhaust fan is shut off and the equipment cooling exhaust OFF light is inhibited.

That's it for air conditioning so we'll finish up with an overview of the aircraft pressurisation system before taking a well-deserved rest.

Our cabin pressure control system includes two identical, automatic CPC's or cabin pressure controllers, available by selecting AUTO or ALTN and also a manual pilot-controlled mode.

The system uses bleed air distributed via the air conditioning system with pressurisation and ventilation controlled by modulating the outflow valve and the overboard exhaust valve.

We also have two pressure relief valves providing safety pressure relief by limiting the differential pressure to a maximum of 9.1psi. 1 negative relief valve prevents external atmospheric pressure from exceeding internal cabin pressure by opening at -1.0psi.

Cabin altitude is normally rate controlled by the CPC up to a cabin altitude of 8,000ft at max certified ceiling, 41,000ft.

Three DC motors can drive the outflow valve giving a high level of redundancy. DC BUS no 1 and DC BUS 2 are controlled by their CPC with the BAT BUS utilised when is manual mode. There is also a safety mechanism on the outflow valve which forces it to close when cabin altitude is above 14,500ft but only when one of the CPC's controls the valve.

The ADIRU's provide ambient static pressure, Baro corrected altitude, non-corrected altitude and calibrated airspeed to both CPC's. The CPCs also receive throttle position and signals from the air/ground sensors. Only one CPC is active at a time, and they swap their roles each flight. Something to remember is that as the CPCs are powered by DC BUS 1 and 2, when there is a total loss of AC power these buses become unpowered, and pressurisation is now controlled manually.

On the ground and inflight with low differential pressure, the overboard exhaust valve is open allowing warm air from the E&E bay to be discharged overboard. In flight at higher differential pressures this valve is normally closed, and exhaust air is diffused into the lining of the forward cargo compartment giving heat to that area.

The overboard exhaust fan will be driven open if either pack switch is in high and the right recirc fan is off. This allows for increased ventilation in the smoke removal configuration.

So, let's take a look at system operation. In the AUTO or ALTN mode the pressurisation control panel is used to input two altitudes into the automatic controllers. FLT ALT, cruise level and LAND ALT, destination airport altitude.

Take off airport altitude which is actually current cabin altitude is fed into the controllers at all times when on the ground. The air/ground sensors feed into the system and when on the ground and at low power, the cabin is depressurised by the outflow valve being driven fully open.

On the ground, at high power settings the cabin begins to pressurise for a more gradual transition to pressurised flight and also to give the system a better response to ground effect pressure changes during takeoff.

In the air the auto controller maintains a proportional differential between airplane and cabin altitude. By increasing the altitude at a rate proportional to airplane climb rate, cabin altitude change is held to the minimum rate required. A little tip I was once told is that in normal operations at 10,000ft in the climb out look for 4-1-4, 400ft rate of cabin climb, 1000ft cabin altitude and 4psi diff pressure and all is going according to plan.

An amber OFF SCHED DECENT light illuminates if the airplane begins to descend without having reached the pre-set cruise altitude. Without further pilot inputs the controller programmes the cabin to land at the takeoff field elevation. This design is for a possible turn back to departure airfield. This can be overridden by matching the FLT ALT window to actual airplane altitude.

Cruise mode is activated when you climb to within 0.25psi of the selected FLT ALT. During cruise the controller maintains the lowest possible cabin altitude based on the programmed differential pressure limits. Below 28,000ft the limit is 7.45psi, 28,000 – 37,000 is 7.80psi and above 37,000ft is 8.35psi.

Descent mode is activated when you descend 0.25psi below the selected FLT ALT. The cabin begins a proportional descent to slightly below the selected LAND ALT so that we land slightly pressurised. This ensures rapid changes in altitude during the approach result in minimum cabin pressure changes.

While taxiing in the CPC drives the outflow valve to fully open thus fully depressurising the cabin.

We'll look at some system lights now and then finish with a quick review of the manual mode operation.

The AUTO FAIL amber light together with the ALTN green light indicates a single CPC failure with the remaining CPC taking over the pressurisation schedule. The ALTN green light alone indicates a manual selection of the backup CPC which will extinguish the AUTO FAIL light.

An AUTO FAIL light alone indicates both CPCs have failed leaving you in Manual control of the pressurisation system.

The conditions for the AUTO FAIL light to illuminate are when DC power is lost, a controller fault, an outflow valve control fault, excessive differential pressure, excessive rate of cabin pressure change or a high cabin altitude above 15,800ft.

The green Manual light illuminates when the pressurisation mode selector switch is positioned in MAN. In Manual mode you modulate the outflow valve position and monitor the cabin altitude panel as well as the outflow valve position on its position indicator. There is a placard below the pressurisation mode selector to help in establishing the cabin altitude for a given flight altitude.

The outflow valve is driven at a slower rate than automatic modes making it quite easy to over control. Outflow valve full range of motion takes up to 20 seconds. The way I like to remember which way this switch for the valve works is by thinking about what your trying to do to the air in the aircraft.

The switch is positioned to the right side of the aircraft so if you push the switch right you're trying to push the air out the window, in other words open the valve and if you push it left you're trying to keep the air inside the aircraft or close the outflow valve. Something that's quite useful to know when in a situation such as a rapid depressurisation.

Talking of a depressurisation. If the cabin altitude reaches 10,000ft the cabin altitude warning activates using the same sound as the take-off config warning but with added CABIN ALT red light illumination. Don't forget about that ALT HORN CUTOUT button on the overhead to silence the horn and keep a semblance of sanity.

On certain models you get a HIGH ALT LDG switch that inhibits the warning up to 15,200ft for use at high elevation airports.

A big subject that one with some time needed to digest all that information and perhaps a couple of listens to take it all in. We hope you are enjoying these systems podcasts and finding them useful refreshers. We'll look to start covering some system malfunctions soon, our theory is we'll try and get through everything when it's working first to give us a good grounding for understanding what will happen when these things perhaps don't behave quite as we'd like.

Thanks again for listening and as always, we'll return in a couple of weeks for more 737 knowledge, tips and trivia. Until then head over to our social media pages and keep the talk going. If you are finding these podcasts useful, please give us one of those all-important reviews and leave us a comment to read out in future podcasts too if you want.