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NARROW-BODY B737NG PASSENGER CONVERSION TO FREIGHTER

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Abstract

Airfreight is an important sector of air transportation and a vital component of the global economy. About 10% of shipped goods worldwide are transported by air. Airfreight moves high-tech goods, mail, livestock and food around the world. Economic activity as measured by gross domestic product (GDP) is a primary driver of the airfreight industry.

Boeing forecasts is that world air cargo will grow at about 4.2% per year (Figure 1).

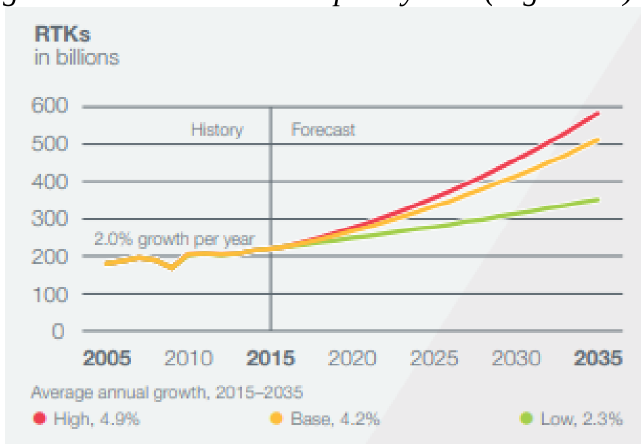

Figure 1: World Air Cargo Forecast

Growing world trade, e-commerce, transport of perishable and time-sensitive commodities, and the need to replace aging airplanes, creates a continuous demand for freighters. Boeing's and Airbus' market outlook suggests that the full freighters fleet will grow to about 3,010 by 2035.

This will only be partly met by production freighters. About 1,440 will be converted passenger airplanes, an economical alternative to new freighters. Short range narrow-body freighters with less than 45 tons payload, existing fleet share of 34% will retain unchanged. Long range large freighters (over 80 tons payload) share, will grow from around 30 percent today, to nearly 35 percent by 2035 while medium freighters (40 to 80 tons payload) share will reduce by 5% by 2035 (Figure 2).

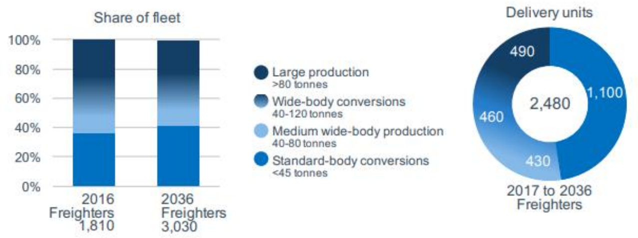

Figure 2: Current Market Outlook 2017-2036

Israel Aerospace Industries (IAI)/BEDEK Aviation Group holds Supplemental Type Certificates (STCs) for conversion of passenger aircraft to BEDEK Special Freighters (BDSF): B737-300, -400BDSF (Classic), and -700BDSF (NG), B747-400BDSF, B767-200BDSF with a 9g safety net and B767-300BDSF with a 9g rigid barrier. Under development are B737-800, -900BDSF and B777-200, -300BDSF.

This paper discusses the Next Generation (NG) narrow-body B737-700/-800/-900 passenger conversion to freighter engineering challenges through structural, new/or modified electrical & mechanical systems and interior modifications required to cope with the certification requirements of B737NG freighter airplanes.

Introduction

Development of the passenger-to-freighter conversion is based on a four-step program:

- Pre-conversion ground and flight tests for data collection including: wing deflections and fuselage pressurization to verify strains at critical loads and locations, and environmental control system (ECS) performance.
- Design of modified structure and interiors, based on finite element models (FEMs).
- Development, qualification and certification of new and modified mechanical, electrical & avionics systems following the guidelines of aviation industry standards, including SAE ARP 4754 (Systems), RTCA DO-160G (Environmental), DO-254 (Hardware), DO-178C (Software), and SAE ARP 4761 (Safety).
- Post conversion ground and flight certification tests to demonstrate airworthiness by verifying modifications compliance with the design requirements and applicable to FAA 14 CFR Part 25 [*Airworthiness standards*: *Transport category airplanes*] regulations.

B737NG modifications consist of the following (see Figure 3):

- Removal of all passenger amenities in the passenger compartment (seats, bins, communications / entertainment systems, lavatories and galleys).
- Deactivation of all doors except doors L1 & R1, retained as entrance and service.
- Strengthening the main deck floor structure.
- Installation of a hydraulically operated main deck cargo door (MDCD).
- Modification of the main deck from passenger configuration to Class "E" cargo compartment (Class "C" in terms of flammability specifications) with an in-flight personnel access.
- The forward & aft lower cargo compartments retain their existing Class "C" configuration consist of fire protection system (1-minute smoke detection & Halon fire extinguishing).
- Addition of a two people supernumerary compartment between the flight deck and the main deck cargo compartment. The added compartment includes escape devices for flight crew & supernumeraries. It also includes all required installations to provide access to the main deck cargo compartment.
- Addition of a 9g rigid barrier and smoke barrier to provide sealing and positive pressure differential provided by the environmental control system (ECS), to protect occupants from smoke, flames and hazardous gases generated in the main deck cargo compartment in case of fire. The barrier is designed to isolate the occupied areas and to meet emergency landing requirements.
- Installation of a floor drain system consists of drain pans, tubing and vent valves to direct fluids towards outboard ports (existing forward and aft drain masts), to prevent water from collecting within the airplane structure and to prevent corrosion.
- Installation of a cargo loading system (CLS), guiding assemblies and restraints.
- Installation of additional seat tracks to provide additional support for the CLS.
- Relocation/rerouting of Captain & First Officer primary static ports flush type and pitot-static tubing to accommodate the main deck cargo door.
- Approving RVSM envelop by performing flight tests using trailing cone.
- Modification of the existing air conditioning system including change of the air distribution ducts while maintaining the existing temperature ranges and 3-zone configuration in the flight deck and forward & aft main deck cargo compartment.
- Addition of Class "E" shutoff valves downstream of the air cycle machines to cut air supply to the main deck cargo compartment in case of fire/smoke in the main deck cargo compartment.
- Replacement of the LH & RH flow control and shutoff valves (FCVs) by new valves with a smoke clearance mode to allow reduced fresh airflow to the occupied areas in case of fire/smoke in the main deck.
- Installation of a new heater enables additional heating capability to the supernumerary distribution system.
- Installation of a new main deck cargo compartment smoke detection system meeting the 1-minute rule detection time required by the latest FAA/EASA regulations.

- Installation of multi-criteria smoke detectors to prevent false alarms due to humidity, dust or other disturbance.
- Addition of main smoke mode based on supplying fresh air to the occupied areas, main deck cargo compartment ventilation shut down, positive pressure differential between the occupied areas and the main deck cargo compartment (to avoid smoke penetration), aircraft depressurization and flight at 25,000 ft for oxygen starvation.
- Installation of new interior which includes lining, dado panels, honeycomb side panels & ceiling, decompression & maintenance panels, window plugs, added decals and markings for the cargo loading system. The new interior should meet most severe flammability procedures required in FAA 14 CFR Part 25 Appendix F Part III [*Test Method to Determine Flame Penetration Resistance of Cargo Compartment Liners*].
- Replacement of the existing main deck fluorescent lighting system by new light-emitting diode (LED) lighting system permanent and flashing type.
- Installation of visual & audible alert system to enable access to the main deck cargo compartment.
- Relocation of the flight data recorder (FDR) and voice date recorder (VDR) to allow access when aircraft is fully loaded with containers.
- Installation of 1-minute lavatory & supernumerary smoke detection system with 2 ambient smoke detectors as required by the FAA/NTSB safety recommendation A-09-53.
- Installation of protective plates on the main deck cargo compartment ceiling to provide an equivalent level of protection for the avionics located between the ceiling and fuselage, to comply with FAA 14 CFR 25.795(c)(2) [*Security considerations*] and the guidelines of AC 25.795-7 [*Survivability of systems*].
- Options:
  - Modification of the temperature control of the main deck cargo compartment to maintain temperature at 2-4°C for perishable goods transport.
  - Installation of sliding carpet loading system (SLC) in the fwd & aft cargo compartment.

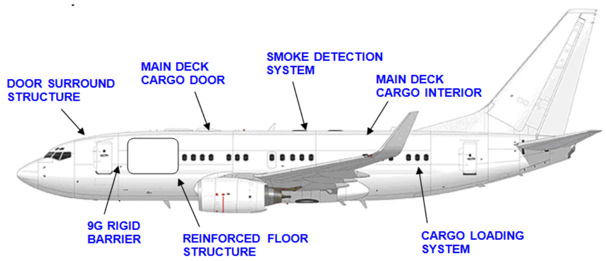

Figure 3: B737-700BDSF Modifications

Regulations

Aircraft manufacturing, operation and maintenance is subject to aviation regulations, standards, procedures and/or criteria which are legally binding the civil aviation community. The widely Federal Aviation Regulations (FARs) issued by the US Federal Aviation Administration (FAA) and certification specifications (CSs) issued by the European Aviation Safety Agency (EASA) are referenced in this paper. Conversion changes a certified airplane. This change does not require a new Type Certificate, but needs to be covered by a Supplemental Type Certificate (STC). The original Type Certificate plus the approved changes in type design equal a STC. The most important regulation for passenger-to-freighter conversion is FAA 14 CFR/EASA CS Part 25 [*Airworthiness Standards, Transport Category Airplanes*].

Freighter conversions are defined as a significant change at product level. The product individual changes are classified according to the FAA guidelines of the changed product rule (CPR). All changes and affected areas comply with the latest amendments except for earlier amendments, but not earlier than the type certificate (TC) amendment level, in the following cases:

- Non-significant changes,
- Applying the last amendment does not contribute to safety or is impractical,
- Secondary changes of a significant change.

Payload - Range Chart

To compare operational characteristics of different aircraft models, payload-range charts are used. The point at the lower right end of the chart (P1) shows ferry range, the aircraft carries no payload and starts flight with full fuel tanks.

Adding payload toward (P2) reduces the range at maximum tank capacity. At (P2) the maximum takeoff weight (MTOW) is reached. To further increase payload towards (P3), the amount of fuel has to be reduced so the range decrease faster per added payload. At (P3) the sum of operating empty weight (OEW) and payload equals the maximum zero fuel weight (MZFW) and further increase of payload is impossible. Reducing OEW but leaving both MZFW and MTOW unchanged, the payload-range chart in the range from (P1) to (P4) of the original aircraft is moved parallel to the payload-axis by the amount of the reduction. Define equipment in the original aircraft as payload on the converted aircraft can drive this (Figure 4).

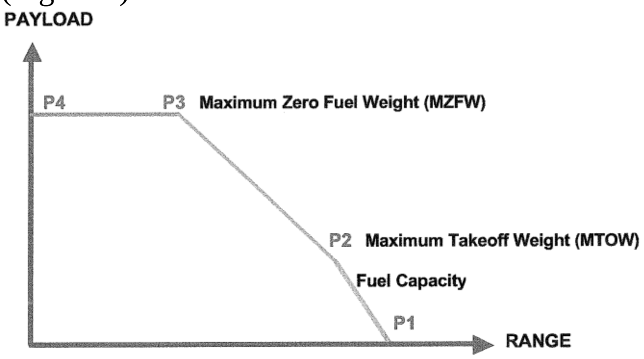

Figure 4: Payload - Range Chart

Flight Deck

Freighter conversion retains unchanged the flight deck configuration except for the following items:

- Deletion of the recirculation fan switches due to removal of the recirculation fan system,
- Added main deck cargo compartment smoke detection control panel,
- Added lavatory & supernumerary smoke detection control panel,
- Added main deck cargo door annunciation.

The new smoke detection systems retain the existing flight deck design and alerting philosophy and the existing color convention of the B737 NG series.

The guidelines of AC 25.1302-1 [*Installed Systems and Equipment for Use by the Flight Crew*] and AC 25.1322-1 [*Flight Crew Alerting*] were used in the design and installation of the controls and displays.

As part of the certification flight testing of the flight deck modifications, the Modified Cooper-Harper Rating Scale (Bedford Workload Scale) was used (Figure 5).

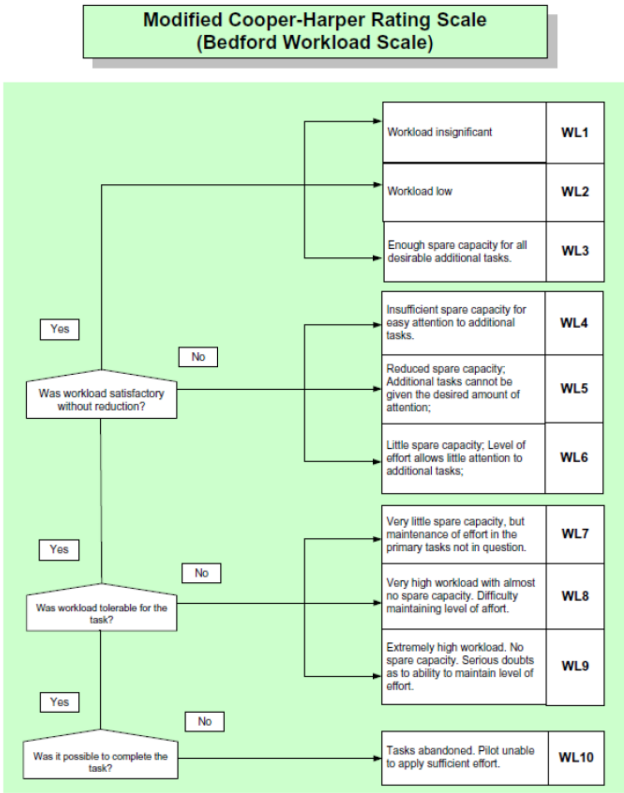

Figure 5: Modified Cooper-Harper Rating Scale (Bedford Workload Scale)

Following the guidance of AC 25.1302-1, the levels of integration, complexity, and novelty of the new main deck and supernumerary smoke detection installation were analyzed, all of which were found to be very low. The systems do not add new technology, do not increase the flight crew workload, do not add operational procedures, do not change the way the crew interacts with other systems, and do not introduce new ways of operating existing systems.

Unit Load Devices

Rapid loading and unloading can be achieved by utilizing loads. Unit load devices (ULDs) include aircraft pallets and containers, which interface directly with the cargo handling and restraint system. ULDs ensure that cargo is moved safely, quickly and cost effectively. An aircraft container is a completely enclosed ULD composed of a base, walls, doors and a roof as assembled panels or as a single shell. An aircraft pallet is a platform with a standard dimensions undersurface on which goods are assembled and secured with a net (Figure 6).

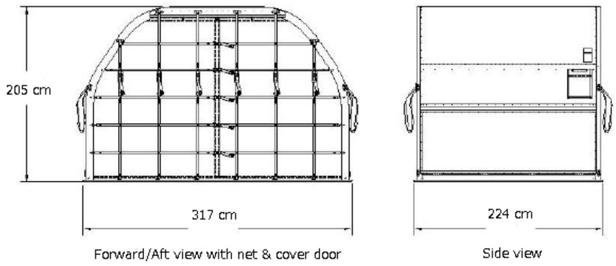

Figure 6: AAA/AAC/AAY Container

Main Deck Cargo Configuration

Several main deck cargo configurations are available to the customer for all freighter conversions to optimize the volume of freighter being loaded into the main deck cargo compartment via the newly installed main deck side cargo door. Modularity is the key word for cargo loading since a whole range of containers and/or pallets may be loaded (Figure 7).

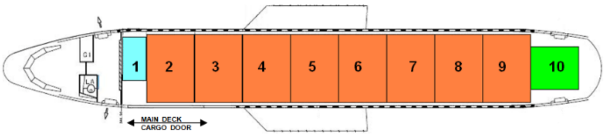

Figure 7: B737-700BDSF ULD's 88" x 125"

Structure Modifications

The structure is modified to support the increase in design weights and high cargo loads in the main deck while retaining the aircraft external geometry, flight characteristics and performance. The changes include replacement/reinforcement of floor beams, posts, seat tracks, intercostals, and floor panels. Addition of new tension ties and frames reinforcements are also part of the structure modifications. Some of the new floor beams are machined from aluminum plate to enhance structural integrity. Fuselage frames are also reinforced (Table 1).

Table 1: Certified Weight Limits

	B737-700 BDSF	B737-800 BDSF
Maximum Taxi Weight (MTW) (lb)	155,000	174,700
Maximum Takeoff Weight (MTOW) (lb)	154,000	174,200
Maximum Zero Fuel Weight (MZFW) (lb)	121,000	138,300
Maximum Landing Weight (MLW) (lb)	129,200	146,300
Fuel Capacity USG/Range naut mi	6,875 / 4,100	6,875/ 3,750
Maximum Cargo Payload (lb)	Up to 45,000	Up to 53,000
Main Deck Pallet Positions	10 8 ULD 88“ · 125“ · 82“ + 1 ULD 80“ · 43“ · 57“ + 1 ULD 88“ · 78.9“ · 62.5“	12 11 ULD 88“ · 125“ · 82“ + 1 ULD 79“ · 60.4“ · 64“

To meet operational targets in terms of cargo capacity and payload revenue, customers can choose between the 9g safety net and 9g rigid barrier configurations designed to prevent movement of containers and meet emergency landing requirements. The 9g rigid barrier allows the operator to load an additional pallet/container due to its shape. A large cutout is performed on the left hand side of the aircraft and replaced by reinforced surrounding structure and the main deck cargo door via segmented hinges.

Several analyses are used for substantiation of the structure modifications. The methodology of substantiation is common to all conversions and includes:

- **Load**: the load analysis ensures no change in the passenger flight envelope, no increase in landing gear loads above the passenger aircraft. Weight and center of gravity limitations are introduced for cargo loading to ensure that the passenger airplane design loads are not exceeded.
- **Flutter**: the flutter substantiation comprises a comparative dynamic analysis of the complete aircraft models before and after conversion, aimed to showing negligible differences in the relevant frequencies and mode shapes.
- **Damage Tolerance**: AC 91-56B [*Continuing Structural Integrity Program for Large Transport Category Airplanes*], AC 25.571D [*Damage Tolerance and Fatigue Evaluation of Structure*] and the structure repair manual (SRM) are used to perform damage tolerance analysis to comply with FAA 14 CFR/EASA CS 25.571. A fatigue spectrum is developed for the freighter versus passenger configuration.
- **Finite Element**: significant structural details and properties of the converted airplane are taken into account to build a finite element model (FEM) and conduct a finite element analysis with a highly accurate loads distribution. The analysis includes various parameters such as internal load, mechanical constraints, 9g forward crash condition, gear loads, flight envelope, main deck floor loads and decompression loads. An internal pressure tests with strain gages instrumentation provide

FEM validation to the structural change on the aircraft structure (Figures 8 & 9).

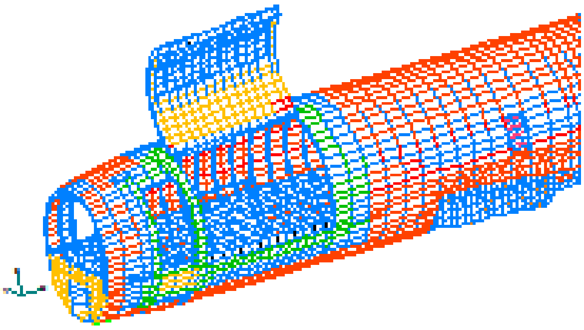

Figure 8: B737-700BDSF Finite Element Model (FEM) with Opened MDCD

Figure 9: B737-700BDSF Cut-Out & Surround

In order to determine the aircraft center of gravity location with reference to the landing gear, the aircraft is first weighed in a level attitude on the wheels; and to determine the center of gravity height, the aircraft is then weighed at different attitudes. This pre-conversion process allows to derivate the aircraft center of gravity position taking into account the aircraft dimensions (Figure 10).

Figure 10: B737 Center of Gravity and Ground Vibration Test (GVT) Evaluation

Main Deck Cargo Door (MDCD)

Main deck cargo door (MDCD) is typically an outwards and upwards opening side door. An upward opening door ensure an easy access to the main deck, reduces the risk of damaging the door or its hinges and to some extent protects the interior from precipitation during ground operations. An isolated hydro-electrical circuit controls the door opening and closing.

Manual operation of the door is normally provided as a backup via manual pump or externally, in case of hydro-electrical failure.

Several catastrophic accidents have demonstrated the need for visual inspections of the door locking mechanism and provisions to prevent depressurization when the door is not fully closed, latched and locked. To ensure pressure equalization across the door prior to opening, a pressure relief door is fitted. Current door designs allow operation in winds up to 60 knots in Canopy position and 40 knots in fully open.

The MDCD has been certified by the FAA to 14 CFR 25.783 [*Fuselage doors*] Amendment 25-88 and by EASA to JAR 25.783 including NPA 25-301 (similar to 14 CFR 25.783 Amendment 25-114). Therefore the MDCD design meets the latest requirements 14 CFR 25.783 Amendment 25-114 May 3, 2004. The MDCD is installed on the left hand side of the fuselage forward of the wing and is hinged at the top.

The door is operated through three mechanisms: lock, latch and lift. Each mechanism is mechanically independent, but hydro-electric sequenced with the other mechanisms in the opening and closing cycles (Figure 11).

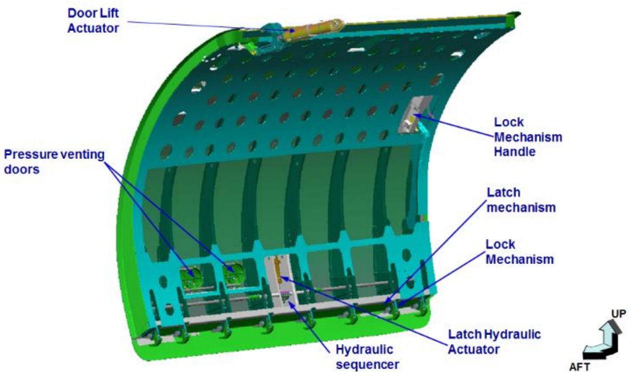

Figure 11: B737 MDCD

The B737 MDCD is hydraulically operated. An aural warning inhibits above the decision speed (V_1) during takeoff. In addition to the indication lights available on the MDCD control panel and to the indication light in the flight deck reporting a potential unsafe condition of the door, several decals are installed on the outside of the MDCD next to each of the locking units to provide the operator a very sharp way to determine whether the door is safe or not. A white flag can be seen at each of the view ports if the locking units have reached their position required for safe conditions.

Environmental Control System

The environmental control system (ECS) is modified to accommodate special freighter configuration by deleting items unique to the passenger configuration (main deck sidewall outlets) and by adding items unique to the special freighter configuration (fire protection related valves) (Figure 12).

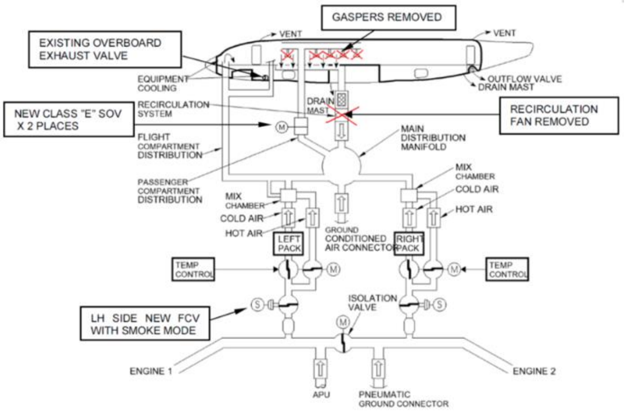

Figure 12: B737-700BDSF ECS

The design approach is to maintain same or better airflow rate, temperature control, duct pressure and noise levels as before the conversion and to meet FAA 14 CFR 25.831 [*Ventilation*] requirements in terms of airflow rate and temperature control.

The modified system successively maintains temperature in the flight deck and the main deck cargo compartment between 19˚C(66˚F) - 29˚C(84˚F), in case of normal temperature selection.

The ECS modifications consist of the following:

- Sidewall ducts and associated outlets are removed.
- Delete entire main deck air distribution system and replaced by all new overhead air distribution ducting.
- Addition of main smoke mode due to firefighting emergency procedures requiring:
  - To shut down ventilation to the main deck cargo compartment via closure of the Class “E” shutoff valves.
  - To activate the air conditioning pack to provide a sufficient amount (reduced airflow) of fresh air to the occupied areas.
  - Addition of a new air conditioning system that includes air heater for supplemental heating of the supernumerary compartment.
  - Simplified the forward electronic equipment (E/E) cooling system to match the freighter aircraft requirements.

The ECS is simplified to provide only fresh air to the different compartments and therefore, there is no need for the cabin air re-circulation system. Therefore, the cabin air re-circulation system and associated control logic and switches are removed.

The air distribution system is balanced and tested to satisfy the defined criteria of success. Fine tuning of the system is performed by introducing screen restrictors thus balancing the airflow delivered to the occupied areas (flight deck and supernumerary area) and to the main deck cargo compartment.

Ventilation

Freighters evolve a problem that is not an issue on a passenger configuration: main deck cargo compartment fire and smoke. FAA 14 CFR Part 25 requires that smoke evacuation from the cockpit area must be "readily accomplished, starting with full pressurization and without depressurizing beyond safe limits". Fire suppression on class “E” cargo compartment requires complete stoppage of airflow to the cargo area in order to minimize oxygen, while still supplying fresh air to the occupied areas to replace smoke in the cabin and sustain a pressure differential across the smoke barrier. As a consequence, modification of the air-conditioning system is necessary. During normal operations, aircraft cabin is fed by a mixture of engine bleed air, conditioned in the air cycle machines and re-circulated cabin air. Air is supplied from the mix manifold separately to the main and flight cabins. The following possible modification options:

- Adding isolation valves to each main deck duct. These valves shut down the airflow in a fire situation to prevent air from entering the main deck. Smoke evacuation and air supply to other areas can be accomplished with the otherwise unchanged system.

- Changing the flow control & shutoff valve (FCV) located upstream of the air-conditioning packs into "smoke mode", allowing just a small amount of fresh airflow to the occupied areas.

Fire Protection

The freighter fire protection consists of fire detection and fire extinguishing/suppression systems as detailed below:

- Detection systems:
  - Engine overheat detection.
  - Engine fire detection.
  - APU fire detection.
  - Wheel well fire detection.
  - Wing overheat detection.
  - Tail cone overheat detection.
  - Main & lower cargo compartment smoke detection.
  - Supernumerary & lavatory smoke detection.
- Extinguishing systems:
  - Engine fire extinguishing.
  - APU fire extinguishing.
  - Main & lower cargo compartment fire extinguishing / suppression.
- Lavatory fire extinguishing.

Common to all conversions, all of the above systems retain unchanged except:

- The addition of a new main deck cargo compartment smoke detection system and fire suppression means in case of fire in the main deck.
- The addition of a new supernumerary & lavatory smoke detection system.

The main deck cargo compartment smoke detection system is a single loop logic, dual channels, and meets the 1-minute rule in case of single channel malfunction. The system 2-LRUs (Line Replaceable Unit) architecture uses a cockpit control panel and FAA Technical Standard Order TSO-C1d approved “ambient” smoke detectors having their sensitivity set to provide an alarm at light transmissibility of 97% (3% obscuration rate). The entire electronics is built in the cockpit control panel.

Photoelectric detectors are used to measure light attenuation, reflection, refraction and absorption of certain wavelengths (Figure 13).

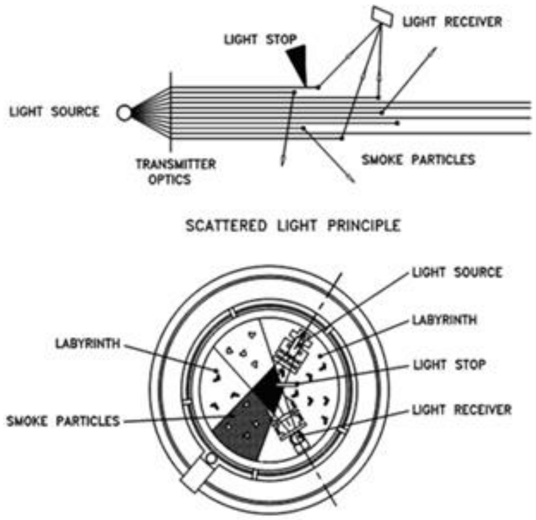

Figure 13: Photoelectric Smoke Detector Architecture

The B737NG BDSF incorporates multi-criteria (MCR) smoke detectors include dual optical chamber, two temperature sensors, and a humidity sensor (Figure 14).

Figure 14: Siemens PMC11 Multi-Criteria (MCR) Smoke Detector

The dual optical chambers allow identification of fire type (open or smoldering) and adjust the sensitivity accordingly. Temperature criteria and humidity criteria combined with optical signals, adjust detector's sensitivity to detect smoke and to prevent deceptive signals due to high humidity variation. The performance of a smoke detector is optimized by adjusting detection logic according to environmental conditions, and smoke properties. Environmental conditions analysis allows smart detection process and thus, significant reduction of false alarms, compared to conventional detectors (Figures 15).

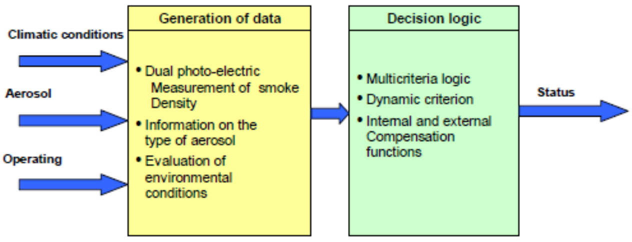

Figure 15: MCR Signal Processing Algorithm

IAI BEDEK, in collaboration with TIMAT (ISRAEL) and Siemens (FRANCE) Airborne Systems, developed state-of-the-art cargo smoke detection systems, for the main cargo and supernumerary & lavatory smoke detection systems. The systems provide:

- Early detection (warning) of fire/smoke at a temperature significantly below structural integrity degradation.
- Functionality test procedure.
- Effectiveness through the entire operation configurations and conditions.
- Comply with 25.1301 [*Function and installation*], 25.1302, 25.1322 and 25.1309 [*Equipment, systems, and installations*] safety requirements.

Considering the probability for a fire event to be less than 1.7 · E-07 per operating hour (OH), system reliability calculations are conducted and compliance with safety requirements of FAA 14 CFR 25.1309 is demonstrated in Table 2.

Table 2: Smoke Detection System Functional Hazard Analysis (FHA)

Fault Conditions	**Classification Severity**	**Requirements (per OH)**
Total loss of smoke detection in combination with a fire	Catastrophic	< 1.00 E-09
Un-indicated loss of smoke detection capability without fire	Major	< 1.00 E-05
Spurious warning of smoke in a cargo compartment	Major	< 1.00 E-05
Total loss of smoke detection in a cargo compartment zone without fire	Minor	< 1.00 E-03

B737-700, -800, -900BDSF main smoke detection system consists of twenty/twenty-six/thirty multi-criteria PMC11 smoke detectors, FAA TSO C1d approved, mounted within recessed cavities on the ceiling panels and a cockpit control panel, located on the P8 Pedestal or P5 aft overhead panel. The new system is integrated into the existing aircraft systems to provide the standard fire alerts and fault indications via the fire warning and master caution lights and annunciator system. It contains a Built-In Test Equipment (BITE) capability for self-checking (Figures 16 & 17).

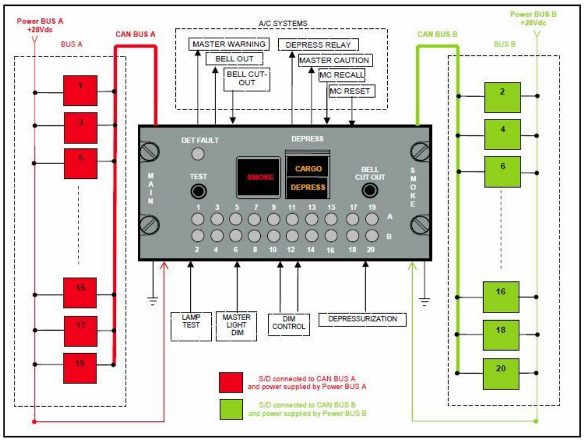

Figure 16: B737-700BDSF Main Deck Smoke Detection System Layout

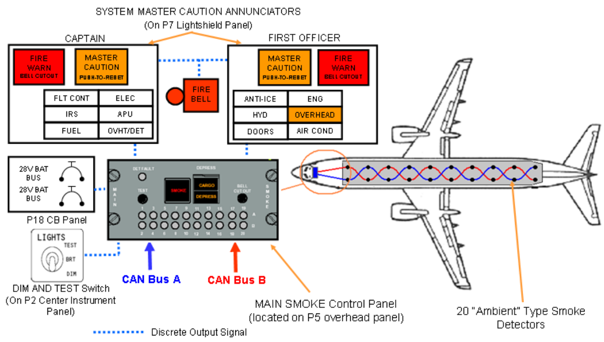

Figure 17: B737-700BDSF Main Deck Smoke Detection System Integration

Smoke detection tests were conducted according to the guidelines of FAA AC 25-9A [*Smoke detection, penetration and evacuation tests and related flight manual emergency procedures*], to demonstrate detection time anywhere within the cargo areas and through the entire aircraft flight envelope. Each test was conducted by generating a small amount of smoke at numerous locations within the cargo compartments. Figure 18 shows a Kidde Aerospace smoke generator producing smoldering smoke according to FAA "suite case" video [*Demonstration of a Typical Smoldering Fire Producing a Small Amount of Smoke*].

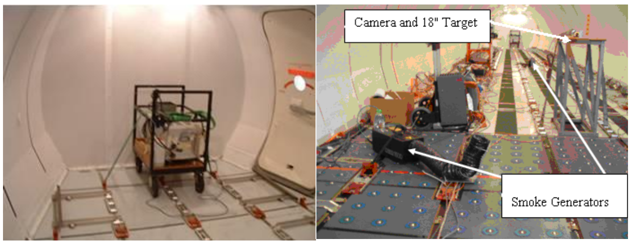

Figure 18: B737NG Smoke Detection and Penetration Ground & Flight Tests

Following the smoke detection tests, a smoke penetration test is conducted, to demonstrate sealing-proofing of occupied areas. The test also supports demonstration of no inadvertent operation of smoke detection for adjacent compartments; smoke is detected only in the compartment where it originates.

Although FAA 14 CFR 25.857 [*Cargo compartment classification*] uses the term "fire extinguishing system", the FAA requires a "fire suppression system" that does not necessarily extinguish fire, but rather suppresses it to ensure safe landing. Currently, the most effective and most commonly used suppression agent is Halon. Although production and usage of Halon is restricted by international agreements due to its effect on the ozone layer, continued use for aircraft fire suppression is supported by the FAA and the US Environmental Protection Agency.

There are different approaches to Halon concentration levels. According to FAA Airworthiness Directive, a minimum initial concentration of 5 percent is required throughout the compartment to suppress combustion to controllable levels, thereafter, the system must sustain a minimum of 3 percent for 60 minutes to prevent re-ignition or spreading of combustion, and for airplanes certified for extended-range twin-engine operations (ETOPS), the fire-suppression system must be able to sustain a 3 percent concentration of Halon within the compartment for a maximum of 180 minutes. However, according to FAA Amendment 25-93, the often-quoted Halon concentration of 3 percent is not a requirement, but is typically used.

A fire-suppression installation typically consists of agent (Halon) bottles, tubing, suppression nozzles, electronic units and a flight deck control panel. Depending on airplane model and its configuration, fire-suppression and detection systems may add up to 300 pounds (136 Kg) to the empty weight of an airplane.

Electrical/Avionics Changes

Aircraft systems changes affect the electrical systems which are modified accordingly. The affected systems include (among others) ECS, smoke detection, communication, lighting, and indications. Electrical system components are removed, modified or changed to support all changes that include: circuit breakers, switches, wire bundles, indications, etc. The wiring design and installation is performed in accordance with Process Specifications which are equivalent to Boeing standards to ensure satisfying quality.

Wires for modified systems are same standard as the existing or an alternative compatible type, in accordance with Boeing D6-54446 [*Standard Wiring Practices Manual*].

The circuit protective devices are compatible with the actual electrical load and wire gage. Six inches clearance between new and modified wires and between wires connected to equipment installed inside of the fuel tanks are kept. The existing wire bundles, located along left side of the aircraft are relocated and rerouted to bypass the main cargo door cutout.

Water & Waste

The conversion airplanes from passenger to special freighter includes the simplification of the basic water & waste system supported by the replacement of large potable water tank by a smaller tank for weight saving as only a limited quantity of water is necessary for freighter airplanes. The B737NG converted freighter potable water system is retained except plugging / removal of unnecessary lines / accessories.

Based on potential customer request, the potable water quantity may be limited by the installation of stand-pipe and/or replacement of water tank envelope together with the adaptation of the water tank quantity indication system (Figure 19).

Existing waste system is retained including the storage tank and service panel. All connections to removed lavatories are plugged (Figure 20).

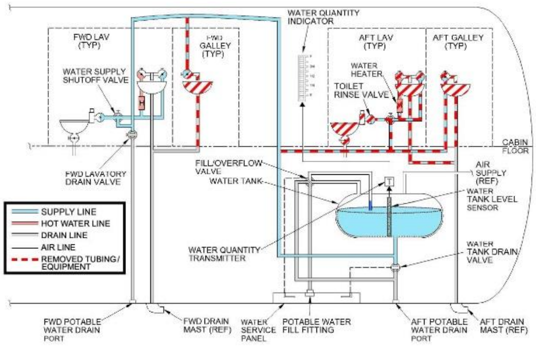

Figure 19: B737NG Potable Water System

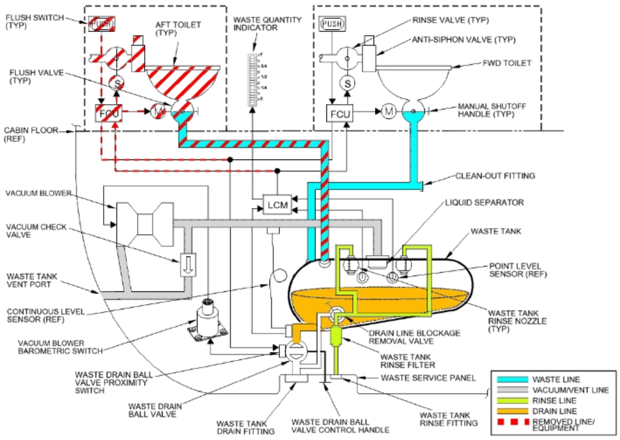

Figure 20: B737NG Waste System

Oxygen Systems

The freighter conversions include the modification of the existing oxygen systems to provide oxygen to the crew and to the supernumeraries at each user inhalation. Passenger system is removed except for installation in the forward lavatory.

The flight crew system is based on single oxygen cylinder located in the forward cargo compartment and on gaseous diluter demand masks available at each flight deck station.

Two oxygen cylinders with two masks are installed on the rigid barrier in front of the supernumerary seats with oxygen consumption 100 minutes in main smoke mode same as the flight crew.

A portable bottle & mask are provided for in flight entry to the main deck cargo compartment in case of required return to seat due to sudden decompression or cargo fire (Figure 21).

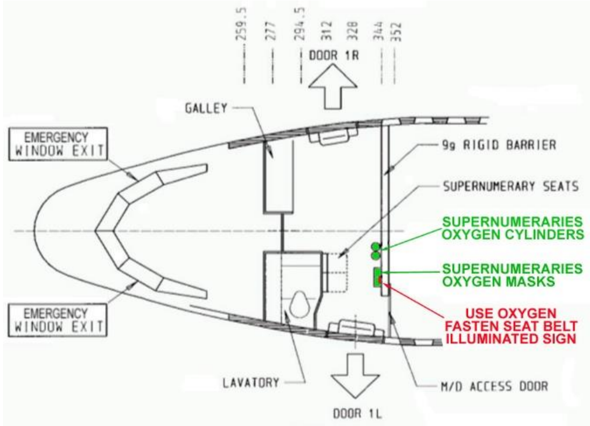

Figure 21: B737NG Supernumerary Oxygen System

Main Deck Cargo Loading System (CLS)

A typical cargo loading system (CLS) consists of necessary equipment to provide movement, guiding and restraint of cargo. The CLS equipment can be attached either directly or via tray assemblies and floor fittings to seat tracks and floor structure. System selection depends, to a certain extent, on how good the ULDs layout with its required restraint installations fits floor structure and seat tracks (Figure 22).


Figure 22: B737NG Cargo Loading System

Elements and layout of a CLS are determined by the fact that a system of ULDs is already used worldwide and by the need to maintain the interlining capability with the system (Figure 23).

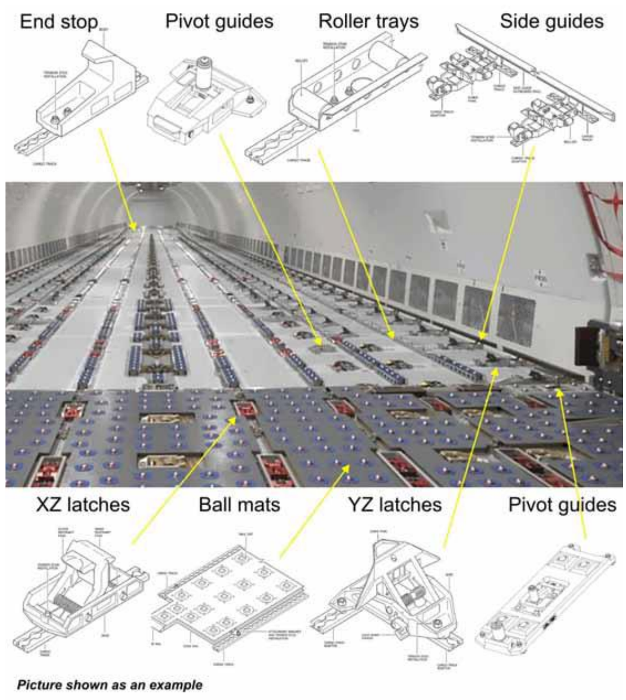

Figure 23: Cargo Loading System (CLS)

Tray assemblies provide moveable restraint for various parts of the CLS like locks and rollers.

Rollers allow free movement of ULDs along tracks in both directions. Brake rollers restrict the movement of ULDs to one direction. They prevent unintended movement of ULDs in cargo compartments with a sloping floor, particularly towards the doorway area.

Pallet locks provide restraint for pallets and containers. Restraint requirements are found in National Aerospace Standard NAS 3610 [*Cargo Unit Load Devices - Specification For*]. The mechanism of longitudinal/vertical restraint locks can be retracted below the roll plane to enable loading and unloading. Tray-mounted locks can be moved along the tracks and locked to them by shear pins. End stop assemblies provide longitudinal and vertical restraint for cargo pallets and containers at the beginning and end of a ULD row. They may be retractable to ease unloading. Outboard guide rails can be installed throughout the aircraft on both sides of the door to protect the fuselage from damage and may contain side locks. Side locks are used to provide vertical and transversal restraint. They are mounted either directly or via fittings onto existing structure. Centerline guide assemblies are installed along the aircraft centerline. They guide and restrain ULDs that are loaded side-by-side along the centerline.

Doorsill protector assemblies are installed at the opening of the cargo door. They are attached to seat tracks by tie down studs and are positioned by shear plungers. These units are hinged to enable upwards folding when not in use. Rollers and caster assemblies are mounted on the doorsill protectors to provide friction-reduced travel for loading and unloading containers. A hinged side guide is mounted on the outside edge of the doorsill protector. The side guide is raised during use to guide containers into the cargo door.

Interior & Cabin Safety

The interior modifications of the main deck cargo compartment consist of:

- A new cargo lining.
- Vent grilles in the dado panels for main deck ventilation flow.
- Dome lights flush mounted on the ceiling for compartment illumination.

All non-metallic materials meet the applicable requirements of FAA 14 CFR 25.853 [*Compartment interiors*] and 25.855 [*Cargo or baggage compartments*] as demonstrated by flammability testing (14 CFR Part 25 Appendix F).

Passenger emergency equipment including life rafts and aft door slides are removed. The existing emergency equipment in the flight deck retain unchanged. TSO approved 4-man life rafts are installed in flight deck. Two TSO approved cabin attendant life vests are retained in their stowage positions for use by supernumeraries.

TSO approved portable ELT is installed on inboard galley wall. 2.5 lbs fire extinguisher is installed on the 9g rigid barrier, adjacent to the galley.

Existing emergency exits for the flight crew and for the supernumerary remain unchanged: forward cabin doors 1L and 1R (including slides) and flight deck LH & RH #2 windows.

Emergency Equipment

The FAA 14 CFR Part 25 requires a number of emergency equipment items. Several already exist, but some major items need to be added. 9g rigid barrier is designed to resist the 9g longitudinal loading of main deck cargo compartment per FAA 14 CFR / EASA CS 25.561 [*General*] (Figure 24).

Figure 24: B737Classic/NG 9g Rigid Barrier and 9g Safety Net

Allowable of material are required to prove the ability of the barrier to withstand the uniform pressure due to load under 9g emergency landing condition. Specimen's tests are performed for bending, shear and compression to evaluate the design values in compliance with FAA 14 CFR 25.613(a)(b) [*Material strength properties and material design values*]. Several tests are conducted to provide enough statistical data for determination of the statistical based design values (Figure 25).

Figure 25: 9g Barrier Shear & Bending Tests

Main Deck Floor Drain

A floor drain system is provided for the main deck cargo compartment. The floor drain is connected to the existing forward and aft drain masts. The forward crew lavatory and galley drain (gray water) is retained. The main deck cargo compartment floor is sealed and water dams are installed along the side walls, aft bulkhead and forward at the anchor beam, to prevent water seepage (Figure 26).

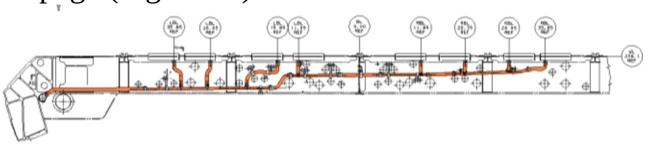

Figure 26: B737NG Main Deck Floor Drain

Rotor Burst

Design precautions are taken to minimize hazards of uncontained engine and auxiliary power unit (APU) rotor failure. Modified items potentially affected by rotor burst are flight control and electrical wires routed in the main deck floor and/or ceiling. All flight controls have backup system, allowing a continued safe flight and landing. Electrical wirings for flight control are located in raceways under the main deck floor beams, away from the risk zone. The design should meet the requirements of FAA 14 CFR 25.903(d) and AC 20-128A [*Design Considerations for Minimizing Hazards Caused by Uncontained Turbine Engine and Auxiliary Power Unit Rotor Failure*].

Method of substantiation consists of a geometrical study demonstrating that the relocated electrical bundles still maintain the physical separation distance from their redundant systems to avoid rotor burst damage (Figure 27).

The modification retains the same potential wire bundle failure combinations as for the original certified aircraft. However, the likelihood of a 1/3 disk hitting either upper or lower wire bundle groups is higher for the STC configuration due to the fact that Wire Bundle Groups are installed closer than for the original certified aircraft.

All possible design options have been reviewed and the design chosen is the most practical solution for re-routing Wire Bundle around the added main deck cargo door cutout by minimizing the hazard caused by flying engine debris.

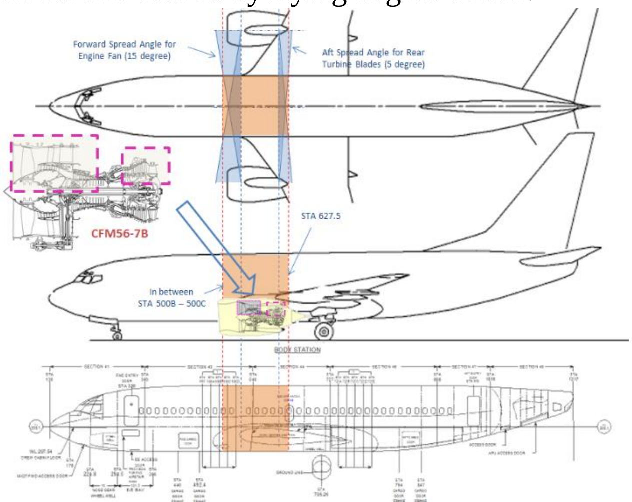

Figure 27: Rotor Burst Affected Areas

All possible design options have been reviewed and the design chosen is the most practical solution for re-routing Wire Bundle around the added main deck cargo door cutout by minimizing the hazard caused by flying engine debris (Figure 28).

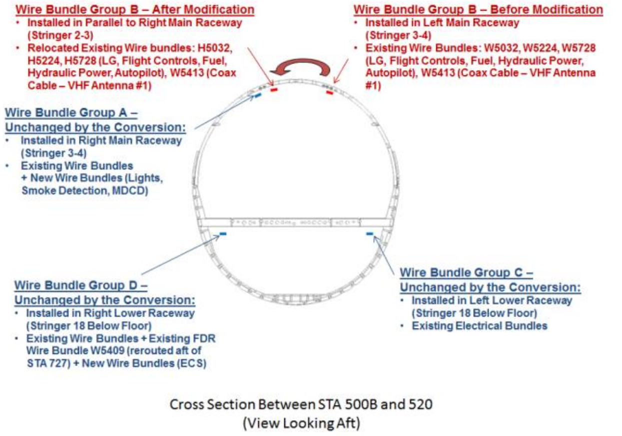

Figure 28: Wire Bundle Routing in Cross-Section

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