Do you wanna see my shock strut?
Analysis of a landing gear

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Summary
The landing gear is a decisive part of an aircraft. The main purposes are absorbing the landing pulse, maneuvering on the ground and providing safe aircraft operations. All the landing gears have the same purposes, but there are a lot of landing gear configurations. The different types of configurations are: conventional gear, single main wheel, bicycle gear, tricycle gear, quadricycle gear and multi-bogey gear. The Boeing 737-800 NG has a tricycle gear. Because the aircraft has a tricycle gear, the gear divides the forces on a bigger surface. Small aircraft often have a fixed landing gear, civil aircraft often a retractable landing gear. In order to gain better aerodynamic conditions and higher efficiency, civil aircraft have retractable landing gears. One of the purposes of the air/ground system is that it makes sure that the landing gear does not retract on the ground. When the landing gear is retract, it is automatically locked, so the gear cannot ‘fall out’ of the storage. In case of emergency, the pilot can extend the landing gear manually. The air/ground system also gives warnings when a malfunction occurs in the system. To absorb the landing shock, shock struts are used. These absorb most of the landing forces by using a compressible gas for suspension and oil for damping. The tires also absorb a bit of the landing pulse. When the aircraft touches down, the aircraft needs to slow down its speed. To slow down the aircraft, the aircraft uses brakes. During full apply of the brakes, they incline to skid. To prevent this, an anti-skid system is used. To maneuver on the ground, a nose wheel steering system is used. Also, to control the landing gear safely, and so the whole aircraft, Boeing has its own requirements. Boeing also published a Master Minimum Equipment List (MMEL), this list prescribed which parts a new landing gear minimally must have for safe operations. Not only Boeing has its requirements, also the European Aviation Safety Agency (EASA) has regulations. It forms regulations to grant aircraft a certification of airworthiness.

Whenever an aircraft lands, takes off, is in a static situation or taxis, different forces are acting on the landing gear. To calculate the amount of force on the landing gear, it is necessary to determine the forces in the critical parts of the landing gear and during ground movements. In order to choose the right construction and materials, it is necessary to perform research. Also inner forces (stress) are applied on the landing gear. These are the forces acting inside the area of the section. After calculating all situations accurately and with a focus on the design and materials, the rejected take-off has proven to be the situation which causes the most stress on the landing gear.

After studying the maintenance program, two malfunctions, which can occur in the landing gear, are chosen. The two chosen malfunctions are the hydraulic and wheel malfunction. The influence on the airworthiness must be examined to prevent the malfunction in the future. When a failure occurs, it must be solved. When a problem occurred and the aircraft is back on the ground, the maintenance crew need to repair the failure and how to prevent it in the future. The financial analysis is an overview of the costs and benefits after adapting the maintenance plant. The extra costs are €707,200 when the maintenance plan is not adapted. So, the benefits are the advantages of the reduction of the operational and material costs.
**Introduction**

Project team 2A2V is given the instruction by ALA to analyze a landing gear of a modern aircraft and conducting a research into possible malfunctions of the landing gear.

This project has some limiting conditions. The team has seven weeks to finish this project. After those seven weeks, on Thursday the 14th of October, a report must be handed over. This report must have a minimum of 30 pages and a maximum of 40 pages. This report consists of three chapters, each of the chapters describe a part of the research process.

In order to start the project, the group chooses the Boeing 737-800 NG as the aircraft to analyze. To understand the principle of the landing gear, the main landing gear and the nose landing gear constructions are processed. The subsystems such as the braking system and the air/ground are convenient to get an overview on how it operates. Also the regulations of the landing gear are processed to complete the analyze (1).

With this information of the landing gear, the forces that acting on a landing gear can be determined. These forces in different situation (taxiing, rejected take off etc.) are analyzed and calculated. After that the several materials and the durability of these material consist in the landing gear are examined (2).

A landing gear deals with several malfunctions. The group analyzes two of these malfunctions after that analysis the group brought solutions to prevent a repeat of these malfunctions. Following with a cost and benefits review on the basis of the analysis of the malfunctions. With all this information the conclusion and recommendation can be make (3).

The main sources for this project are: college’s period 5 and the project book of period 5. For the structure of this report Wentzel (2009) is used. The complete bibliography and the appendices are found at the end of the report.
1. Landing gear analysis

Aircraft use landing gears ever since the first flight was made. In the beginning of the twentieth century landing gears were simplistic, had no wheels and were not retractable. During the Second World War, landing gears have been developed; became retractable and the configuration changed. As a result of the increasing aircraft dimensions and weight more developed gears were needed. Nowadays, all commercial aircraft use complex landing gear systems that are retractable. All landing gears serve the same purposes (1.1). During landing, the landing gear must absorb the landing shock (1.2). During taxi the nose gear is steerable to maneuver on the ground (1.3). To reduce drag, the landing gear is made extendable and retractable (1.4). After the touchdown, the aircraft decelerates by the use of brake systems (1.5). All landing gear system components must meet several regulations to guarantee safety aircraft operations (1.6).

1.1. Introduction landing gear

To understand the operation of the landing gear systems it is needed to analyze the main purposes of a modern landing gear (1.1.1). The lay-out of different landing gears and especially the lay-out of the Boeing 737-800 NG landing gear is described (1.1.2). In that way, the location of the landing gear systems is shown.

1.1.1. Purposes and goals

Landing gears come in different types and dimensions, but they all have the same purposes:

1. Absorbing the landing pulse
2. Maneuvering on the ground
3. Safety aircraft operations

ad1 Absorbing the landing pulse

When an aircraft touches down, the vertical velocity has to be totally reduced. The landing gear of modern aircraft absorbs the landing pulse and thereby reduce the aircraft vertical speed to zero.

ad2 Maneuvering on the ground

The landing gear provides the possibility to maneuver on the ground. The engines enable acceleration or deceleration of the aircraft and the brake landing gear components decelerate the wheels.

ad3 Safety aircraft operations

The aircraft fuselage is supported by the landing gear, whereby the aircraft’s fuselage is distributed on the ground. The landing gear also protects the aircraft fuselage and prevents aircraft damage with creating a space between the fuselage and the ground.

1.1.2. Configuration

The configuration of landing gears is based on the number of wheels that the landing gear consists of. To give an overview of the different types of landing gears that are used in aircraft, the different types are described (1.1.2a). The Boeing 737-800 NG landing gear structure is important when describing the subsystems that are related to the landing gear (1.1.2b).

1.1.2.a Landing gear types

Dependent on the aircraft type and the purpose that the aircraft serves, different landing gear configurations are used. Light aircraft use more simple landing gear configurations, large commercial aircraft use more complex landing gear configurations. The main landing gear configurations are (appendix I):

1. Conventional gear
2. Single main wheel
3. Bicycle gear
4. Tricycle gear
5. Quadricycle gear
6. Multi-bogey gear

ad1 Conventional gear
A conventional landing gear consists of two main wheels located at both sides underneath the nose and one small tail wheel. The configuration is often used in small piston-engine aircraft. The tail wheel causes less drag and the construction is relatively light.

ad2 Single main wheel
This configuration consists of a main gear and a small tail wheel. Both gears are located at the centerline. This landing gear configuration often has outriggers underneath the wings to stabilize the aircraft. For some aircraft, the outriggers have to be installed by the airport crew before taxiing. The single main wheel configuration is used for light aircraft like gliders and sailplanes.

ad3 Bicycle gear
A bicycle gear consists of two main gears that are situated on the centerline of the aircraft. One gear is situated underneath the nose and the second gear is situated at the back, behind the center of gravity. Outriggers under the wings prevent the aircraft from overturning. This configuration is useful for aircraft with long and small fuselages. The bicycle gear is light and the lock up compartment is small. This gear configuration is relatively unstable and the pilot prevents the outriggers from touching the ground. The bicycle gear is often used for bomber aircraft with a wide wing span.

ad4 Tricycle gear
The most used landing gear configuration which consists of one nose gear and two main gears which are located just behind the center of gravity. The tricycle gear is a stable design and easy to steer. It provides better visibility over the nose and the aircraft loading is much easier. The disadvantage of this configuration is the larger weight and the increase of drag. When loading the aircraft, the load must be distributed over the aircraft to prevent tail tipping. Configuration used for many commercial aircraft, for example the Boeing 737-800 NG.

ad5 Quadricycle gear
The quadricycle gear is almost similar to the bicycle gear, but the quadricycle consists of two nose gears and two main gears that have an equal design. The gear turns in other directions during crosswind landings. Cargo aircraft often use the configuration, because the quadricycle aircraft are close to the ground. The quadricycle generates more drag than the bicycle gear and weighs more.

ad6 Multi-bogey gear
In a multi-bogey gear configuration, multiple wheels are fastened on one beam, a bogey. The nose gear consists of two legs with two wheels each. The main gear consists of bogeys with multiple wheels. The advantage of the multi-bogey gears for larger aircraft is the pressure spreading over the ground: the forces on each tire are minimal.

1.1.2.b Landing gear Boeing 737-800 NG
The Boeing 737-800 NG landing gear is a tricycle type landing gear (figure 1). The main landing gear consists of two legs which have two wheels each. The nose gear (1) is a two wheel construction, the wheels are much smaller than those of the main landing gear (2).

![Figure 1: Landing gear B737-800 NG](image)

Legend:
1. Nose gear
2. Main gear
The nose landing gear is stored in the fuselage and the main landing gear is partly stored in the wings and the fuselage. The lay-out of the landing gear is analyzed to get an overview of the design of the landing gear. The main landing gear (figure 2) contains a down lock strut (1) that is responsible for the retraction and extension of the landing gear. The down lock strut is fastened on the side strut (2) which bears the gear when it is extended. The shock strut is used for absorbing the landing pulse (3). A door control rod (4) actuates the doors (5) that cover the landing gear when it is retracted. The tires (6) contact the ground and provide a small part of the damping of the landing pulse. The aircraft decelerates by the use of disc brakes on the wheels (7).

The nose gear mechanism (figure 3) is similar to the main gear mechanism, however the nose gear has a steering mechanism which is needed while taxiing. The nose gear extends or retracts when the lower drag strut is actuated (1). Doors that are situated at both sides of the nose gear cover the landing gear when it is retracted (2). Steering control cables (3) actuate the landing gear steering mechanism. The steering mechanism is covered to protect the steering mechanism components (4). An actuator amplifies the supplied steering forces (5). The shock strut absorbs the landing pulse (6) and the tires connect the aircraft to the ground (7).

1.2. Shock absorbing and damping

The main function of the shock absorbers and the dampers is to reduce the vertical component of the aircraft velocity to zero during landing. The kinetic energy of the aircraft generated by the vertical speed has to be converted to heat. The second function is to enable comfortable taxiing. In small aircraft with fixed landing gears, the construction elasticity offers enough shock absorption. Larger commercial aircraft need an elaborated system,
a shock absorption system (1.2.1). Information about the landing gear is obtained by the use of an air/ground logic sensor system and is indicated in the cockpit (1.2.2).

1.2.1. Shock strut and torque links
The shock strut system is responsible for absorbing the landing pulse, which consists of damping and suspension. The system component that is responsible for absorbing and damping is the oleo strut, which works with oil and a compressible gas (1.2.1a). The shock absorbing system of a Boeing 737-800 NG is more complicated. The system consists of oleo struts and several related components (1.2.1b).

1.2.1.a Oleo strut principles
The oleo strut system (figure 4) consists of a piston (1) filled with compressible nitrogen (2) that moves in a cylinder (3). The mediums are separated by a seal, the nitrogen and oil (5) do not mix and that prevents foam in the cylinder. An acting force moves the piston and compresses the nitrogen and causing an oil flow through the orifices (5). The oil is uncompressible and practices the damping. The nitrogen is compressible and practices the suspension of the landing pulse. When the nitrogen is compressed, the pressure increases, whereby the cylinder moves and the shock strut rebounds. The orifice opening is variable, so the shock absorption and damping are different in landing and taxiing. Multi-stage shock absorbers capture more load than single stage shock absorbers. The multi-stage absorbers contain a double acting system that pressurizes the air amongst low pressure first, then pressurization at high pressure occurs. The double compression system enables better suspension characteristics.

![Figure 4 Oleo strut](image)

1.2.1.b Shock absorption Boeing 737-800 NG
The shock strut of the Boeing 737-800 NG consists of an oleo strut system with various supporting subsystems (appendix II). An inner cylinder which is fastened on the main gear axle (1) moves in an outer cylinder (2). The strut action is controlled by the nitrogen and the oil. The gas charging valve practices the pressurization of the nitrogen gas in the shock strut (3). The oil charging valve allows for hydraulic servicing in the shock strut (4). Installed components reduce influences on the shock strut and assist with the shock strut operation. The walking beam decreases forces of the actuators that work on the structure. The walking beam (5) is fastened on the aircraft with a walking beam hanger (6). The reaction link transfers most of the load that works on the side strut (7) up to the end of the shock strut (8). Thus, the load acting on the side structure is minimal. The reaction link is connected to the shock strut and to the main gear up lock brackets (9). The inner cylinder of the shock strut tends to rotate in the outer cylinder. The torsion links (10) are installed to prevent this rotation and these also permit the up and down movement of the inner cylinder in the outer cylinder. The torsion links consist of two components, an upper and a lower link that are connected in the center of the shock strut. The upper link is fastened on the outer cylinder and the lower link is fastened on the inner cylinder. The shimmy damper (11), which decreases the vibrations between the inner and outer cylinder, is connected to the lower torsion link. The vibrations between the cylinders occur at high speed taxi and heavy brake use. To maintain the wheels and tires a
jack pad (12) is used, connected at the bottom of the shock strut. The jack pad allows upwards movement of the inner cylinder.

1.2.2. Air/ground logic

In order to control all the landing gear systems a “management” system is built in. This management system is called the air/ground system which is a logic system. A logic system requires various signals in order to work (1.2.2a). One of the main sensors of the air/ground system is called a Proximity Switch Electronics Unit (PSEU). This unit controls different parts of the air/ground system (1.2.2b). To keep the flight operations as safe as possible multiple indicators are installed to warn the pilots when a system failure occurs (1.2.2c).

1.2.2.a Logic systems

The air/ground system is a logic system. The main purpose of a logic system is to actuate a large system using signals of smaller systems. The most common form of a logic system is a cycle which repeats the same steps when it gets an input (figure 5). A logic system works almost similar to an electrical circuit. An electrical circuit requires an input to let the system work. When the system has processed the signal it provides an output whereupon the input signal returns to its communicator. As told is the air/ground system almost similar to the electrical system except the air/ground system needs additional steps. Different signals can serve as inputs. The input can be the pilot who uses the brakes which leads to a signal to the braking system or it can be as simple as moving a lever in the cockpit. The air/ground system needs an input in order to work. An input (1) will been given to the system one. System one will convert the signal if necessary (2). This converts the signal in an output (3). The output will be the input for system two (4) system two is the system which will actuate in this case the brake system (5). When the brake system is in motion several sensors and indicators provide information to the PSEU about the position in which the brake system resides (6). The information the indicators provide will be available in the cockpit (7). With this information the pilot can decide if the system is working properly (8). In case the system is not doing exactly what it should do the input can be renewed and the system will start all over again. The air/ground system is a system which is built in to prevent human flaws when it comes to actuating the systems of an aircraft.

1.2.2.b PSEU

The air/ground system does not only consist out of systems which can actuate moving parts, it also consists out of many sensors and indicators. One of the main parts of the air/ground system is the PSEU. This part communicates with many different indicators and sensors. Communication between aircraft systems is not its only purpose. The PSEU has different purposes:

1. Control
2. Warning and communication.
Control

The most important task of the PSEU is controlling different parts of the air/ground system by sending signals to these parts. The PSEU controls six systems and it receives multiple signals from different sensors. There are two systems that use these signals from the sensors. These systems are of vital importance for the functioning of the air/ground system. System one and two use the information from the sensors and the discrete configuration signals. With these configuration signals the systems create several outputs which are used by multiple aircraft systems. There are many different systems which are actuated by system one, these systems differ from the systems which are actuated by system two (appendix IV and V). The PSEU provides several other signals to other parts of the air/ground system, these other parts are called the air/ground relays. There are many different types of relays in an aircraft: the types which are important for the air/ground system are the ground mode relays and the air mode relays. Both relays can only be used when they are in their designated mode. The air/ground relays are controlled by the PSEU. The PSEU sends the relays a signal when their designated mode is activated. When the relays receive the signal they activate their system. When the system is activated the pilot can use the systems function. Per example when the aircraft is in air mode the PSEU sends this information to the reverse thrust relays, the relays receives the information and activate the system. The pilot can now choose to use the reverse thrust. There are many different relays which are actuated by the PSEU (appendix VI and VII). The locations of the junction boxes which hold the relays are mainly located near the landing gear (appendix III).

Warning and communication

As told the PSEU is also a system which can warn the pilots whenever a fault occurs. The PSEU checks the systems with the help of a Build In Test Equipment (BITE). The BITE checks the system for faults. When the system detects a fault the PSEU alarm light in the cockpit will light up. These faults need to be resolved before the aircraft can take off. The PSEU light is not the only warning system that is included in the complex system of a Boeing 737. The cockpit contains for each fault a separate indicator. The cockpit contains per example an indicator about the position of the speed brakes and the landing gear. These faults are all exposed thanks to the indicators which send their information to the PSEU. The PSEU receives the information and communicates with the warning indicators in the cockpit. The indicators light up and the pilots notice that something is not right. During the time the fault is resolved the PSEU keeps on monitoring every part of system one and two for more faults.

1.2.2.c Indicators

Multiple indicators are installed to keep the aircraft operations as safe as possible. There are different types of sensors:

1. Pressure sensors
2. Temperature sensors
3. Movement sensors

Pressure sensors

There are sensors which need pressure in order work; mostly these sensors are applied for the instruments in the cockpit. These sensors measure the air pressure which surrounds the aircraft and by using this air pressure, the sensors can deliver a measurement to the instruments in the cockpit. The PSEU use the pressure signals in order to configure the other elements of the air/ground system. The second place where a pressure sensing sensor is installed is at the tires. The tires need to have a specific tire pressure in order to keep the operation as safe as possible.

Temperature sensors

There are sensors which measure temperature. These sensors are used in the brake system. A sudden deceleration can cause a rise in temperature. The braking system cannot overheat that is why these sensors are installed in the braking system. The temperature sensors are installed in the cockpit and in the cabin for the passengers and the pilots comfort. The sensors communicate with the PSEU. In case the pilots experience the temperature as too hot they can activate the air-conditioning relays through the PSEU.
Movement sensors

This type of sensor uses the pressure on the landing gear for its measurements. When the aircraft lands a strong force works on the landing gear. This force is pushing the landing gears strut back into its cylinder. The information that the aircraft is on the ground is received by the PSEU. The PSEU activates the ground mode relays allowing the pilot to use every system which can be controlled in ground mode.

1.3. Maneuvering on the ground

An aircraft maneuvers on the ground using the tires which are installed on the landing gear. The wheels are an important part because otherwise it would not be possible to move the aircraft. There is no way to maneuver an aircraft on the ground without the tires (1.3.1). If the aircraft has wheels which all aim at the same direction, the only direction the aircraft can move is straight forward. When the aircraft takes a left or right turn it is not possible because the wheels are all in the same direction. So the aircraft needs a way to steer, this can be done with the nose landing gear. Using the nose landing gear the aircraft is able to make turns left and right (1.3.2). When aircrafts getting bigger in size, the more wheels they get. The main landing gear is not able to steer in any direction. So the wheels want to slip across the asphalt. To avoid the sliding, it is possible to steer some of the main landing gear wheels. Except the Boeing 737-800 NG has no main gear steering so the Boeing 737-800 NG cannot steer its main landing gear.

1.3.1. Wheels and tires

The tires (1) of every aircraft are designed to withstand maximum aircraft weight. The total weight of the aircraft is carried by multiple parts of the landing gear. The forces are distributed between the wheels (2) and the axis (3). The wheels are attached to the axis and the axis is attached to the shock strut (figure 6). The number of wheels depends of the size and weight of the aircraft.

The nose landing gear and the main landing gear are not the same, at the main landing gear (1.3.1a) the force of the aircraft is bigger than at the nose landing gear (1.3.1b). So the wheels and tires cannot be the same. The tires are made out of more materials than rubber; if the tire was made only from rubber the tire would be too weak and too flexible. The tires are not allowed to consist any oxygen, because oxygen is inflammable. Therefore the tires are filled with nitrogen. There are two types of tires for aircraft, bias tires (1.3.1c) and radial tires (1.3.1d). These types differ in the structure of the tire. Each tire has its own characteristics and benefits.

1.3.1.a Nose landing gear wheels

The nose landing gear has two tires and wheel assemblies (figure 7). The wheel consists out of two pieces, an inner wheel half (1) and an outer wheel half (2). These two pieces are secured with wheel tie bolts (3). In each wheel there is a tire inflating valve (4) and an over pressure relief valve (5). Both valves are located in the outer wheel half.
1.3.1.b Main landing gear wheels

The main landing gear consists out of two parts, one landing gear on the left side of the aircraft and one landing gear of the right side of the aircraft. Each landing gear consists out of two wheels. The main landing gear wheels (figure 8) are made of inner (1) and outer (2) wheel halves. Tie bolts (3) hold the two halves together. The brake rotor drive (4) and the heat shields (5) are in the inner wheel half of each wheel. Each wheel has a tire inflation valve, an over pressure relief valve and four thermal fuse plugs (6). The inflating valve and the releasing valve are both located in the inner wheel half.

1.3.1.c Bias tires

Bias aircraft tires (appendix VIII and IX) are specially designed for aircraft and have alternate layers of rubber coated with ply cords which extend around the beads. Alternate angles are substantially less than 90° to the center line of the tread, the layers lying in all kind of ways. The tire consists out of many parts. The features of Bias tires is that the tires has a unique cord body shape and a specially compounded tread design and which create a large contact area. The benefits of the Bias tires are when the aircraft is approaching the runway with a higher speed the tire gives more performance and capacity, the tire reduces stress as the tire cycles from tension to compression. It performs in a wide range of operating conditions.

1.3.1.d Radial tires

Radial tires (appendix IX and X) are specially designed for aircraft. These tires have a flexible casing which is constructed out of rubber coated ply cords. These rubber coated ply cords extend around the beads and are substantially at 90° to the centerline of the tread. The casing is stabilized by an essentially inextensible circumferential belt. The characteristics of the radial tire are: the tire is very strong because the rigid tread belts consist out of enhanced rubber. The benefits are that the radial tire can take on more landings compared to the bias tire, the radial tire reduced weight compared to the bias tire and the radial tire gives more stability for longer life.

1.3.1.e Safety

When the pressure in the tire gets to high the over pressure valve relieves pressure. The relief valve releases only the excess amount of pressure in the tire when the pressure is more than 375-450 psi (26-31 bar) for the main landing gear and 375-450 psi (26-31 bar) for the nose landing gear. The over pressure relief valve must be replaced when it has released the pressure. The four thermal fuse plugs in the main landing gear located in the inner wheel half prevent tire explosion caused by hot brakes. These plugs melt to release tire pressure at approximately 380°F (193°C). The fuse plugs need to be replaced when they are melted.
1.3.2. Nose landing gear steering system

In order to steer the aircraft the pilot needs to be able to move the nose wheel. This is possible by turning the steering wheel and by operating the rudder pedals (figure 9). When the pilot moves the steering wheel (1) full travel, the nose wheels turn a maximum from 78° in the left or right direction. When the rudder pedals are moved in full travel on the ground, the nose wheels turn a maximum 7° in the left or right direction. The signals from the steering inputs go to the metering valve through a cable loop. Before any signal is going further, the alternate nose wheel steering switch (2) has to be put on.

When the aircraft is in the air, the air/ground system activates air mode (figure 10). The air/ground system (1) activates the air mode relays which sends power to the rotary actuator (2). The rotary actuator moves the eccentric drum to air position. This moves the clutch arm away from the steering crank and will not let any movement of the rudder pedals move the clutch arm (3). Rudder pedals inputs do not move the steering actuators (4).

When an aircraft is on the ground, the air/ground system activates ground mode. The air/ground system activates its ground relays and sends power to the rotary actuator. The rotary actuator moves the eccentric drum to ground position. This moves the clutch arm in contact with the steering crank stops and permits movements of the rudder pedals to move the clutch arm and then move the steering quadrant. A movement of the steering wheel moves the control cable and steering quadrant. When the steering quadrant turns, the clutch arm contacts...
the steering crank stops and extends the centering spring. Because the centering spring in the rudder system is stronger than the centering spring in the pedal steering mechanism, the steering crank will not move. A movement of the steering wheel does not back drive the rudder pedals. The steering metering valve (figure 11) (1) controls the hydraulic flow to the steering actuators (2). The steering actuator consists two parts, each part is a cylinder which can extend and can retract by means of hydraulic pressure controlled by the metering valve. To provide that the actuators are going to move instead of the nose wheel tires (3), they are divided into two plates: the upper steering plate (4) and the under steering plate (5). The end of the actuator is connected to the shock strut (6).

![Diagram of nose wheel steering system]

Legend:
1. Steering metering valve module
2. Steering actuator
3. Nose wheel tire
4. Upper steering plate
5. Under steering plate
6. Shock strut

Figure 11  Nose wheel steering system

1.4. Extension and retraction
The drag on an aircraft has to be minimal. Therefore the Landing gear can retract. The pilots use a landing gear lever that is part of the landing gear control system (1.4.1). Both the main landing gear and the nose landing gear extend and retract in a different way. The main landing gear retract sideways (1.4.2) and the nose landing gear retracts in the same direction of flying (1.4.3). There is always a possibility of a failure. Therefore the pilots have the assistance of a warning system (1.4.4).

1.4.1. Landing gear control system
The landing gear control system controls the extension and retraction of the landing gears. It consists out of several components. First, the pilot gives an input signal through the control lever assembly (1.4.1a). This signal is transmitted by cables via the control lever forward quadrant (1.4.1b) through the landing gear selector valve (1.4.1c). The selector valve opens a valve which causes the hydraulic fluid to flow to the landing gears. This hydraulic fluid comes from two hydraulic systems and goes to the transfer valve (1.4.1d).

1.4.1.a Control lever assembly
The control lever assembly is located in the cockpit where the pilots can operate the landing gear (appendix XI) by first pulling the landing gear control lever and then moving it up or down. The control lever can be moved in up, off or down position. To prevent that the control lever is moved in up position when the aircraft is on the ground, a mechanical lock is fit into the control lever assembly, which is controlled by a solenoid lock. When the aircraft is released from the ground, the solenoid lock retracts and the mechanical lock gets disabled where the gear lever can be put in the up position. On the control lever, a push-pull cable is located. By moving the control lever, the cable will move. The cable goes to the forward control quadrant.

1.4.1.b Forward control quadrant
The forward control quadrant is located beneath the cockpit in the equipment compartment of the nose wheel landing gear (appendix XII). The forward control quadrant is mounted to the cable from the control lever. When
this cable moves, a gearbox in the forward control quadrant makes a cable move that goes to the landing gear selector valve.

1.4.1.c Selector Valve
The landing gear selector valve is located in the equipment compartment of the left main landing gear (appendix XII). The cables from the forward control quadrant are fit on the rod of the selector valve. When the control lever moves, the rod moves through the cables so a valve opens and closes. This causes hydraulic pressure to flow from the transfer valve to the extension and retraction system of the landing gears.

1.4.1.d Transfer valve
Two hydraulic systems are connected to the landing gear control system (appendix XIII). These are called hydraulic system A and hydraulic system B. Hydraulic system A supplies pressure for extension and retraction, hydraulic system B supplies pressure for retraction only. The transfer valve is connected with these two systems and lets only one system flow hydraulic pressure fluid to the selector valve. Hydraulic system A is changed with system B if one of the following conditions occurs:

- Aircraft is airborne
- Landing Gear is up and locked
- One main landing gear is not up
- Left engine N2 is less than 50 percent
- Hydraulic system B pressure is supplied to transfer valve

1.4.2. Main landing gear extension and retraction system
The extension and retraction system is controlled by the LG control system. The retraction system unlocks the down-lock mechanisms, retracts the landing gears and locks the up-lock mechanisms (1.4.2a). The extension system unlocks the up-lock mechanisms, extends the landing gears and locks up the down-lock mechanisms (1.4.2b). The manual extension control mechanism allows the pilots to extend the landing gears when the normal operating system fails (1.4.2c).

1.4.2.a Retraction system
For the retraction of the main landing gear the landing gear control system is operative. When the landing gear lever is up, the rod on the selector valve is opened so that hydraulic pressure fluid flows to the main landing gear extension and retraction system. In the main landing gear retraction system it first flows through the transfer cylinder. The transfer cylinder delays the fluid that goes to the main landing gear actuators. This makes the main landing gear down lock actuators unlock the down lock mechanism before the gears start to retract upwards. A restrictor decreases the flow of hydraulic pressure fluid to the main landing gear actuators when the landing gears get to the up position. Eventually an up lock mechanism locks the landing gears so they stay in the up position. The main components of the retraction system are:

1. Transfer cylinder
2. Main landing gear down lock actuators and mechanism
3. Main landing gear actuators
4. Main landing gear up lock mechanism

ad1 Transfer cylinder
The transfer cylinder delays the extension and retraction of the main landing gear by letting the hydraulic fluid of the main landing gear actuator flows along a cylinder with a piston in it (figure 12). The left side of the piston is connected to the up pressure fluid and the right side is connected to the down pressure fluid. When only up or down pressure flows, it pushes the cylinder to the side that does not have pressure. This delays the hydraulic pressure current which goes to the main landing gear actuator, so the actuator starts moving.

![Figure 12 Transfer cylinder](image.png)
ad2 Main landing gear down lock actuators and mechanism
To down lock the main landing gear a mechanism is fit on the landing gear (appendix XIV). The down lock mechanism is placed vertical between the upper side strut and the reaction link of the landing gear. To lock and unlock this mechanism an actuator is placed horizontal between the mechanism and the top of the upper side strut (figure 13). When the landing gear is extended the upper and lower side strut are in line with each other. The down lock mechanism holds these struts inline by the actuator that applies a force on the down lock mechanism in horizontal direction. Two springs prevent that the down lock mechanism is pushed too far away from the actuator. When the landing gear lever is selected for retraction the actuator pushes the mechanism out of vertical position to unlock the down lock mechanism.

ad3 Main landing gear actuators
The main landing gear actuator is fit beneath the walking beam, outboard of the main landing gear shock strut (figure 14). The rod of the actuator is placed on the main landing gear trunnion which is fit on the shock strut (appendix XV). The head end of the actuator is fit on the beam hangar which is attached on the structure of the wing. When the actuator is extending, it applies a force through the actuator rod against the main landing gear trunnion which causes a moment on the shock strut axis. This force also applies a reaction force in the cylinder of the actuator, which is transmitted through the walking beam of the landing gear to the other part of the main landing gear trunnion, which also causes a moment on the shock strut axis. This provides enough force to rotate the main landing gear around the shock strut axis which makes the main landing gear retract.

The main landing gear actuator has a restrictor in the up pressure line that controls the amount of fluid. When the landing gear gets into the up position, the restrictor decreases the amount of hydraulic pressure fluid so the actuator stops moving.

ad4 Main landing gear up lock mechanism
The main landing gear up lock mechanism holds the landing gear in the up position (appendix XVI). It is fit inboard of the shock strut. There is one up lock mechanism for each main landing gear. The mechanism consists out of a hook that goes into the up lock roller that is located on the shock strut. Two lock springs hold the mechanism in the up and locked position. During retraction the roller on the shock strut moves into the up lock mechanism and locks itself. Then the main landing gear is locked.

1.4.2.b Extension system
The extension of the main landing gears is not very different from the retraction system. First the landing gear control system is operative. When the landing gear lever is down, the rod on the selector valve is opened so that hydraulic pressure fluid flows to the main landing gear extension and retraction system. In the main landing gear extension system it first goes through the transfer cylinder. The transfer cylinder delays the fluid that goes to the main landing gear actuators. This makes the main landing gear up lock actuators unlock the up lock mechanisms before the gears start to retract downwards. After the main landing gear is unlocked, the actuator starts moving. A restrictor decreases the flow of hydraulic pressure fluid to the main landing gear’s actuators when the landing gears get to the up position. Eventually, the down-lock mechanisms lock the landing gears so they stay in the down position. The components that are operating different from the retraction system are:

1. Main landing gear up lock actuator
2. main landing gear actuator

**ad1 Main landing gear up lock actuator**
Each main landing gear has its up lock actuator (figure 15). The up-lock actuator only operates when extension is selected for the landing gears. When the landing gear lever is moved to the down position, the actuator experiences hydraulic pressure and the piston moves into the cylinder head. The rod of the actuator moves inwards and puts the up-lock mechanism into the unlock position. The main landing gear can now be extended.

**ad2 Main landing gear actuator**
During extension, the main landing gear actuator operates in the same way as when retracting the landing gears. The only difference is that the main landing gear actuator rod is pushed in the opposite direction, which causes the opposite moments on the shock strut axis, so the main landing gear gets rotated in the opposite direction.

### 1.4.2.c Manual extension control mechanism (back up)
Hydraulic system A supplies hydraulic pressure for the main landing gear extension and retraction systems. Hydraulic system B only supplies alternate hydraulic pressure for the retraction system (appendix XVII). In case system A fails, the normal landing gear extension is not available, the manual extension control mechanism provides mechanical backup for the extension of the landing gears.

The manual extension control mechanism for the main landing gear consists out of two handles, which are fit in the floor of the cockpit compartment beneath an access door. These handles are connected to cables that go through a cable quadrant, beneath the cockpit, to the main landing gear extension linkages. By pulling a handle the cable on it will pull the quadrant that is fit in the main landing gear extension linkages. When the quadrant moves the control rod moves and the lever turns. The lever puts the up lock mechanism into the unlocked position. Now the landing gear will extend by gravity.

When the access door to the manual extension control handles is opened an electrical signal is transmitted to the bypass valve on the landing gear selector valve. The selector valve moves the bypass valve in the bypass position. Now all the hydraulic pressure fluid goes to the hydraulic system return, so the hydraulic system components do not prevent the main landing gear to lock during free-fall extension.

### 1.4.3. Nose landing gear extension and retraction system
The nose landing gear consists out of various parts (appendix XVIII). The extension and retraction of the nose landing gear is controlled by the nose landing gear actuator (1.4.3a). The locking mechanism causes the nose landing gear to be in a fixed position (1.4.3b). The hydraulic pressure in the lock actuator is controlled by the valve manifold (1.4.3c). To make sure that the nose landing gear and the doors do not collide during the extension or retraction there is a transfer cylinder in use (1.4.3d). Using all the various parts it is possible to operate the nose landing gear (1.4.3e).

**1.4.3.a Nose landing gear actuator**
The nose landing gear actuator (figure 16) is used to retract and extend the nose landing gear. This is perceived by using hydraulic pressure. When the nose landing gear is in down lock position and needs to be retracted than the hydraulic system puts pressure on the outer side (1) of the actuator. This causes the actuator to extend and push the nose landing gear up.

When the nose landing gear needs to extend the down pressure (2) is higher than the up pressure causing the nose landing gear to go down.

---

Legend:
1. Up pressure
2. Down pressure
1.4.3.b Lock
The lock system uses an over center lock to secure the nose landing gear in a fixed position. Therefore there are two parts installed on the nose landing gear:

1. Lock actuator
2. Lock mechanism

ad1 Lock actuator
The lock actuator uses the same type of system as the nose landing gear actuator. But in this case the actuator needs to retract when the nose landing gear retracts. The lock actuator is used to unlock the nose landing gear when the retraction begins and it is used to lock when the nose landing gear is completely retracted.

ad2 Lock mechanism
The lock mechanism (appendix XIX) causes the nose landing gear to lock in its over center lock. When the over center lock is reached the two bungee springs keep the mechanism in over center lock.

1.4.3.c Valve manifold
The valve manifold is used to control the hydraulic pressure to the nose landing gear actuator. It has two pressure relief valves that control the pressure. When the pressure in the hydraulic system reaches 3150 psi the valve opens to keep the pressure below 3150 psi.

1.4.3.d Transfer cylinder
The transfer cylinder (figure 17) causes a time delay between extension and retraction of the nose landing gear. This is achieved by adding a compartment (1) which connects the up (2) and down (3) pressure. When retracting the nose landing gear the up pressure is high. This causes the surface of separation (4) to shift to the down pressure, because the up pressure is higher than the down pressure. When shifting the surface of separation, this creates more room for the hydraulic pressure to fill the compartment. This causes the pressure to rise slower than in the nose landing gear actuator. This has as effect that the nose landing gear is unlocked by the nose landing gear actuator before the nose landing gear starts to retract.

1.4.3.e Operation
The nose landing gear can be operated in three different ways:

1. Retraction
2. Extension
3. Manual extension

ad1 Retraction
The landing gear lever is in up position. This causes the hydraulic pressure to increase in the up pressure lines. The transfer cylinder causes a delay between the nose landing gear actuator and the lock actuator. When the pressure in the nose landing gear actuator is at its maximum, the lock actuator unlocks the nose landing gear. Then the Landing gear keeps going up until the lock actuator locks the nose landing gear inside the fuselage. Then the lever is put in the off position causing the hydraulic pressure to decrease in order to level the up and down pressure.
Extension

The landing gear lever is put in the down position. This lets the transfer cylinder cause a pressure gap between the nose landing gear actuator and the lock actuator. When the pressure is at its maximum, the gear is unlocked by the lock actuator. The landing gear completely retracts until the lock mechanism locks the nose landing gear. The pressure is kept on the system, in order to keep the nose landing gear in its extended position.

Manual extension

When the hydraulic pressure fails, there is only one way to extend the nose landing gear. This is done by hand. When there is no pressure in the hydraulic system, the pilot needs to pull a string. This string is attached to the lock mechanism. When this string is pulled out, the over center lock releases and the gears drops down due to gravity and gets smashed into its lock by the drag that is created by the airflow.

1.4.4. Landing gear position indication and warning system

The pilots need to know if the landing gear is retracted or extended in order to land the aircraft safely (1.4.4a). If the LG does not extend during the landing, there is a warning system that acknowledges the pilots of the retracted LG (1.4.4b).

1.4.4.a Position indication

Boeing 737-800 NG uses several sensors that provide information about the landing gear’s position. The sensors send the signal to the PSEU that sends a signal to the indication lights on the instrument panel in the cockpit. The LG lever has two sensors that register whether the lever is in up or down position (appendix XX). The main landing gear uses four sensors. These are used for the up lock and the down lock mechanisms (appendix XXI). The nose landing gear uses two sensors. These sensors are both used for the up and down lock mechanisms (appendix XXII). When the sensors of the LG do not send a signal, for example during the extension and the retraction, a red light illuminates on the instrument panel. When the LG is locked in up or down position, a green light illuminates on the instrument panel.

1.4.4.b Warning system

When the gear is not down and locked, the warning system will start to acknowledge the pilots that the gear is still up. Before the warning system start to use the horn, there are several conditions that need to be met. Condition one states that when the gear is up and the flaps selection is zero till ten units, the thrust levers are set for landing and when the radio altitude is 200 till 800 feet. Than the horn will start to sound. When this condition is met, the pilots can deactivate the horn using the horn cutout switch. Condition two states that when the gear is up and the flaps selection is zero till ten units, the thrust levers are set for landing and when the radio altitude is less than 200 feet the horn will start to sound. In this case, the pilots are not able to deactivate the horn. Condition three states that the gear is up and the flaps selection is 15 till 25 units, the thrust levers are set for landing, the horn will start to sound. The pilot is not able to stop the horn. Condition four states that when the gear is up and the flaps selection is 25 or more. Than the horn will start to sound and cannot be switched off.

1.5. Deceleration

Besides the fact that the landing gear should make it possible to carry the aircraft during ground maneuver, it should also give the aircraft the possibility to decelerate in ground mode. In small aircraft it is possible to decelerate the aircraft using only manpower. With a Boeing 737-800 NG the needed brake forces are too high to be controlled by the crew’s manpower. For this reason this aircraft is equipped with a hydraulic brake system to decelerate the aircraft (1.5.1). The main brake-system of this aircraft can be divided into several sub-systems: The auto-brake system which makes it easier for the crew to decelerate the aircraft (1.5.2), the anti-skid system which prevents skidding of the wheels (1.5.3) and a parking-brake system which makes it possible to park the aircraft (1.5.4).
1.5.1. Hydraulic brake system
The Boeing 737-800 NG uses hydraulic pressure to control the main landing gear brakes (appendix XXIII). Within the hydraulic system of a Boeing 737-800 NG different types of brake systems can be distinguished (1.5.1a). Each of these systems work differently (1.5.1b).

1.5.1.a Brake systems
The brake systems can be divided into:
1. Normal brake system
2. Alternate brake system
3. Accumulator brake system

ad1 Normal brake system
The normal brake system uses the hydraulic system B to operate the brakes. This system is only used during a normal situation (a situation without errors).

ad2 Alternate brake system
The alternate brakes are operated by hydraulic system A when there is a malfunction in the normal brakes. Another function of the alternate brakes is stopping the wheels before entering the wheel well, so they do not cause damage. An actuator is used to trigger the alternate brakes without moving the input shaft.

ad3 Accumulator brake system
This system is activated when hydraulic system A and B do not deliver pressure or when the pressure is below the minimum required. The fluid in the accumulator is not enough to generate 3500 psi and when this pressure is lower than the pressure in the fluid, the fluid ensures that the pressure remains high. The system gets charged energy in the normal and alternate brake mode. When these systems do not work, the accumulator brake delivers pressure for six stops or it operates the parking brake for eight hours.

1.5.1.b Operation
The hydraulic system B or A sends pressure to the normal or alternate brake systems when this happens the accumulator isolation valve holds pressure in the brake accumulator in case of emergency (appendix XXIII).

1.5.2. Auto brake system
The auto brake system stops the aircraft during a rejected take-off or when the aircraft lands. There are five auto brake components: the antiskid/auto brake control unit (1.5.2a), the auto brake select switch (1.5.2b), the auto brake pressure control module (1.5.2c), the auto brake shuttle valve (1.5.2d) and the auto brake disarm amber light (1.5.2e).

1.5.2.a Antiskid/auto brake control unit
The antiskid/auto brake control unit controls the auto brake system. The auto brake control unit gets input from several sources:
1. Auto brake pressure control module
2. Speed brake arming switch
3. Auto throttle switch packs
4. Auto brake shuttle valve

1.5.2.b Auto brake select switch
The auto brake select switch provides six options to select a rate of deceleration (figure 18). The rejected take-off option (3) gives full pressure to the brakes to make a stop. The rejected take-off only works when the pilot makes a rejected take-off at a speed more than 80 knots. With the Off command (2) the auto brake system is not active. In normal position (1) there are different deceleration rates with different amounts of pressure (table 1).
Legend:
1. Normal position
2. Auto brakes off
3. Rejected take-off

Figure 18  Auto brake select switch

<table>
<thead>
<tr>
<th>Auto brake select switch</th>
<th>Deceleration rate (ft/sec²)</th>
<th>Brake pressure (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4</td>
<td>1285</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>1500</td>
</tr>
<tr>
<td>3</td>
<td>7,2</td>
<td>2000</td>
</tr>
<tr>
<td>MAX</td>
<td>12-14</td>
<td>3000</td>
</tr>
<tr>
<td>Rejected take-off</td>
<td>Not controlled</td>
<td>Maximum</td>
</tr>
</tbody>
</table>

Table 1  Auto brake select rates

1.5.2.c Auto brake pressure control module
The auto brake pressure control module sends pressure to the normal brake system. Hydraulic system B supplies pressure to the auto brake control module. This works as follows: the AACU sends signals to the solenoid valve and to the control valve to start the auto brake’s pressure. With the hydraulic pressure the solenoid valve and the control valve operate. These valves deliver pressure to the brakes.

1.5.2.d Auto brake shuttle valve
The auto brake shuttle valve sends pressure to the normal brake system when the normal pressure is less than the auto brake pressure. The pressure switch on the auto brake shuttle valve sends signals to the antiskid/auto brake control unit.

1.5.2.e Auto brake disarm amber light
The auto brake disarm amber light illuminates when the pilot selects auto brakes and if one of these following conditions occur: a malfunction in the auto brake system or a malfunction in the antiskid system.

1.5.3. Antiskid system
The main purpose of this system is to prevent slipping of the wheels. The antiskid system makes it possible to apply maximal braking force independent of runway conditions. Based on functioning of the anti-skid system two modes can be distinguished, namely: normal mode and alternate mode. The normal mode is active on each main gear wheel. If an error may occur in hydraulic system B, the anti-skid system will automatically switch to alternate mode which is powered by hydraulic system A. The alternate mode works slightly different compared to normal mode. In alternate mode the anti-skid system is active on each main gear wheel pair instead of each main gear wheel. The anti-kid system has several functions: skid control (1.5.3a), locked wheel protection (1.5.3b), hydroplane protection (1.5.3c), touchdown protection (1.5.3d), gear retract inhibit (1.5.3e).

1.5.3.a Skid control
If the speed of one or more wheels is less, in comparison to the other wheels, the brake pressure on that wheel will be reduced causing the skidding to stop.

1.5.3.b Locked wheel protection
This protection is only active when the wheel speed is more than 25 kts. The system compares the speed of the two inboard or two outboard wheels. If one of these two pairs move slower than the other, the brake pressure on that pair will be reduced.
1.5.3.c Hydroplane protection
Hydroplaning occurs when an aircraft lands on a runway with standing water. This standing water (comparable with a puddle of rainwater) exists over the runway on spots where the aircraft touches down. When the aircraft touches down with the vertical touch down speed, hydroplaning could occur. In such a situation, the tires do not touch the ground, but they keep floating with a certain speed over the water. The tires do not experience the friction of the runway, so applying full brakes has no effect. If the ground speed of the aircraft is more than the wheel speed, the brake pressure will be reduced. Also, to prevent this situation, the aircraft can touch down more severe, so the wheels will press the water aside and the wheels experience the friction of the runway.

1.5.3.d Touchdown protection
This protection prevents wheel brake operations when the aircraft is still airborne. Therefore, an aircraft can never touch down with blocked wheels.

1.5.3.e Gear retract inhibit
This protection makes the alternate anti-skid system inoperative during landing gear retraction.

1.5.4. Parking brake system
This system is used to park the aircraft so that the pilot does not have to provide continuous pressure on the brake pedals. The parking brake is activated by pressing the brake pedals down and simultaneously pulling the parking brake lever up. To deactivate the parking brake the brake pedals have to be pressed again until the brake lever goes down. If for any reason the thrust levers are pushed forward, the “take-off configuration” will illuminate and its horn will sound.

1.6. Regulations
In order to control the landing gear safely and so the whole aircraft, Boeing has its own requirements how they want pilots to control Boeing aircraft safely (1.6.1). But first a new aircraft must be certified by the European Aviation Safety Agency (EASA), to guarantee safe operation. New landing gears encounter several tests and when they pass these tests, the landing gear is airworthy (1.6.2). The Master Minimum Equipment List (MMEL) is a list made by Boeing, in which is prescribed which parts a new landing gear minimally must have for safe operations (1.6.3).

1.6.1. Boeing’s operational requirements
The requirements of Boeing are of great importance since their company made the Boeing 737-800 NG. The operational requirement consists out of two different subsections. The first subsection contains checklists. Checklists are made for every phase during the flight from start till the end (1.6.1.a). The second subsection contains the lists of limitations. This list ensures the safety of the flight operation at all times (1.6.1.b).

1.6.1.a Checklists
During flights pilots need to monitor every meter and positions of the handles. All the checking of the positions of the handles or meters can become very exhausting and confusing for the pilot. This is why the aircraft manufacturer has introduced checklists. These checklists are made for the safety of the pilots and the passengers (appendix XXIV). For every phase of the flight there is a checklist. There are four checklists which are important for the landing gear these checklists are:
1. Take-off
2. Decent
3. Approach
4. Landing

1.6.1.b Limitations
Every aircraft has limits (appendix XXV). The pilots may never exceed these limits because these limits are set for the safety of the flight operations. The limitations contain not only the limits of the aircraft it also contains the
information about certain conditions in which the aircraft may not fly. The limitations are divided in different subsections, these subsections are:

1. Operational limitations
2. Airspeed limitations
3. Electrical limitations
4. Flight control limitations
5. Miscellaneous limitations
6. Weight limitations

**ad1 Operational limits**
These limitations focus on the operation of the aircraft. Included in these limitations are the limits which may not be exceeded. Examples of limits which are included in the operational limitations are maximum altitudes, wind limits, runway conditions and visibility conditions.

**ad2 Airspeed limitations**
These limitations focus on the airspeed of an aircraft. The aircraft may never go faster than the maximum airspeed which is set by the manufacturer. The airspeed limitations are not only limits about the speed of the vehicle, it is also about certain functions which may not be activated with different speeds. For example the landing gear may not be extended when the airspeed is more than 320 kts.

**ad3 Electrical limits**
The electrical limitations are about: what the frequency of the integrated drive generators (IDG) may be, how many IDG there may be, what the voltage may be and what the rated output may be.

**ad4 Flight control limitations**
The limits for the flight controls are the conditions in which several components of the flight controls may not be used. When the aircraft is flying on high altitude levels, icing can occur. In these conditions the flaps may not be used. The flaps may be extended when the aircraft does not exceed the altitude maximum of 20,000 ft.

**ad5 Miscellaneous limitations**
The miscellaneous limitations are mixed limits. This means the miscellaneous limitation contain various limits. None of these limits are specific about one component of the aircraft.

**ad6 Weight limitations**
These limitations fully focus on the weight of an aircraft. The weight of an aircraft may not be too heavy to take off or to land. This is why the maximum takeoff weight (MTOW) and the maximum landing weight are introduced.

### 1.6.2. Authorities’ requirements

In document Certification Specification 25 (CS-25) of the EASA, the regulations of the landing gear are named. Book 1, where these regulations are written, is called: ‘Airworthiness Code’. So if an aircraft meets EASA’s requirements, this aircraft is airworthy. EASA subdivides these regulations for the landing gear in: general (1.6.2a), shock absorption tests (1.6.2b), retracting mechanism (which is subdivided in six categories) (1.6.2c), wheels (1.6.2d), tires (1.6.2e), brakes and braking systems (which is subdivided in eleven categories) (1.6.2f) and nose wheel steering (1.6.2g).

#### 1.6.2.a General

The landing gear must be constructed so that if it collapses due to overload during take-off and landing, the possible spillage of fuel must not cause a fire hazard. If the aircraft fails to extend its landing gear before a landing, the construction must be made so that when the aircraft slides over the paved runway, no fuel must be lost to cause a fire hazard. Constructors of the aircraft must show these capabilities in tests and/or analysis.
1.6.2.b Shock absorption tests
Constructors of the landing gear must show that the landing gear dynamic characteristics are enough to perform safe flights. The maximum energy absorption volume must be greater than the energy the aircraft will ever produce during landing and take-off. Also the landing gear must show its capability of acting in its reserve energy absorption capacity, during a 3.7 m/s descent, where 3.1 m/s is the maximum descent speed in normal touch down.

1.6.2.c Retraction mechanism
The requirements of the retraction mechanism are subdivided in six categories:
1. General
2. Landing gear lock
3. Emergency operation
4. Operation test
5. Position indicator and warning device
6. Protection of equipment on landing gear and in wheel wells

ad1 General
The retraction mechanism of a landing gear must be designed for all loads which can work on the retraction system, even at different speeds and flight phases.

ad2 Landing gear lock
The landing gear must be kept extended in flight and on the ground. In flight, the landing gear must be kept in the correct retracted position and it must be shown that the extended landing gear and/or doors are not dangerous, when the aircraft fails to keep it in retracted position.

ad3 Emergency operation
When the landing gear fails to operate properly, emergency indicators must show this failure to the pilots.

ad4 Operation test
Operation tests must show that the landing gear’s retraction mechanism functions properly.

ad5 Position indicator and warning device
Emergency/warning indicators must be mounted in the cockpit so that pilots can easily notice them. The indicators must be designed as follows: the indicators may be placed in the closeness of the landing gear control lever and must be located and coupled to the mechanical systems of the landing gear. The indicators must give the pilots continuous or periodical warnings when a failure occurs and they must warn on time, so the pilots have enough time to perform alternative landing gear lock-down or to make a go-around. False warnings and landing gear position indications must be minimized.

ad6 Protection of equipment on landing gear and in wheel wells
Bursting tires, loose tire treads and rising wheel brake temperatures may not cause unsafe operation of the landing gear and damage in wheel wells.

1.6.2.d Wheels
Approval of all wheels (both main landing gear and nose landing gear wheels) is needed. The wheels must be designed and tested so that the maximum static load rate of each wheel will not be less than the corresponding static ground reaction. There must be means of the pressurization of the tires on the wheels, to prevent burst.

1.6.2.e Tires
Every wheel must be fitted with a tire, which speed and load rate is approved by the manufacturer to operate under every critical condition. This is done by testing main landing gear wheels with the aircraft’s maximum weight, under the center of gravity and the ground reactions. For the nose wheel tires it is necessary they are
placed so (with respect to the center of gravity) that the loads on the nose wheel tires are as favorable as possible. The dimensions of the tires must be designed so that they will not contact any part of the retraction/extension system or structure of the landing gear. In addition, tires mounted on wheels of an aircraft with a maximum certificated start weight of 34,019 kg must be inflated with an inert gas, like nitrogen. This inert gas must not contain more than 5% oxygen by volume of the tire.

1.6.2.f Brakes and braking systems

The requirements of the brakes and braking systems are subdivided in eleven categories:

1. Approval
2. Brake system capability
3. Brake controls
4. Parking brake
5. Antiskid system
6. Kinetic energy capacity
7. Brake condition after high kinetic energy dynamometer stop(s)
8. Stored energy systems
9. Brake wear indicators
10. Over-temperature burst prevention
11. Compatibility

ad1 Approval
Each constructional combination of wheels and brakes must be approved.

ad2 Brake system capability
The brakes and brake systems must be constructed and designed so that if a failure in the electrical, pneumatic, hydraulic or mechanical system occurs, the pilots are still able to stop the aircraft with a braked roll stopping distance not longer than two times the predetermined landing distance. Also if hydraulic fluid is lost, it may not cause a fire hazard.

ad3 Brake controls
The brake controls must be constructed and designed so that excessive control forces for operation are not necessary and if auto brake systems are installed, the pilots can arm, disarm and override this system.

ad4 Parking brake
If an aircraft is in static position, rolling must be prevented on a dry and level paved runway. The parking brakes must keep the aircraft still, also when the engines are on idle or full power. The control must be suitable located in the cockpit and there must be indication of parking brake status.

ad5 Antiskid system
The antiskid system must operate properly over the expected runway conditions and the system must have the priority over the automatic brake system.

ad6 Kinetic energy capacity
Each aircraft must be tested for its design landing stop brake kinetic energy, its maximum kinetic accelerate-stop and its most severe landing stop requirements of each wheel, brake and tire:

- The design landing stop is a normal operation stop with the maximum landing weight. The brakes must absorb enough kinetic energy and with that, the energy absorption rate must be determined and compared with the manufacturer’s rate. The mean deceleration must not be less than $3.1 \text{ m/s}^2$.
- The maximum kinetic accelerate-stop is a rejected take-off for the most critical combination of aircraft landing weight and speed. When the pilots decide to perform a rejected take-off, the brakes must give enough brake force. This rate must be determined and compared with the manufacturer’s rate. The mean deceleration must not be less than $1.8 \text{ m/s}^2$. 
• The most severe landing stop is a stop at the most critical combination of aircraft landing weight and speed. It must be shown that the brake heat sink, the wheel, brake and tire assembly is able to absorb all kinetic energy.

The amount of kinetic energy per wheel may also be determined with a direct calculation at the commencement of the braking maneuver, instead of the above mentioned rational analysis of the brakes (formula 1):

\[
E_K = \frac{1}{2} m v^2 \quad E_K = \text{Kinetic energy per wheel (Joule)}
\]

\[
m = \text{aircraft mass (kg)}
\]

\[
v = \text{aircraft speed (m/s)}
\]

\[
N = \text{number of main wheels with brakes.}
\]

Formula 1 Kinetic energy

However, this calculation may only be used under the following conditions:

• The landing flap conditions are already approved.
• Unequal braking distributions must be taken into account. For instance, both main landing gear braking and nose wheel braking is used.
• Runway crown must also be taken into account. Runway crown is a runway design where the centerline lies higher than the edges of the runway, so (rain) water can escape and hydroplaning, grooves and porosity can be prevented. This is because, when runway crown is applied, landing gear brakes situated in the middle of the aircraft (such as the nose wheel and the inner main landing gear wheels) have more aircraft load to carry than the outer wheels. Consequently, these inner brakes have to brake more, than the outer brakes. This could cause unreliable calculations.
• For determining the design landing stop, the aircraft speed may not be less than \( \frac{V_{REF}}{1.3} \) or \( V_{SO} \). \( V_{REF} \) is the aircraft steady landing approach speed at the maximum design landing weight and in the landing configuration at sea level.

ad7 Brake condition after high kinetic energy dynamometer stop(s)
After three minutes of full application of the brakes, it must be demonstrated that after 5 minutes of standing in parking brake, no fire hazard has occurred in the brakes, wheels and tires.

ad8 Stored energy systems
If a stored energy system is used, means of it must be shown to the flight crew. The available stored energy must be enough for six full applications of the brakes, when the antiskid system is not operating. Also it must be enough for bringing the aircraft to a complete stop, with the antiskid system operating under all runway conditions.

ad9 Brake wear indicators
An indication about worn brakes are required. These indicators must be reliable and readily visible.

ad10 Over-temperature burst prevention
Every tire with a brake must have temperature indicators to prevent wheel failure and tire burst, which could cause a fire hazard.

ad11 Compatibility
Compatibility of the wheels and brake systems with the aircraft must be substantiated.

1.6.2.g Nose wheel steering
In nose wheel steering tests must be shown that it does not need any exceptional skill for using it, during any failure and under every flight condition. Nose wheel steering must not interfere the retraction and extension mechanism, in any practical circumstances. Under any failure, the nose wheel steering system in use must not cause any dangerous effect. In addition, damage must not be made to the nose wheel steering system when towing the aircraft on the ground.
1.6.3. Master Minimum Equipment List (MMEL)

The MMEL (figure 19) (appendix XXVI) is a list of all the components of an aircraft (1). The MMEL contains not only the instruments or components the aircraft contains; it also contains how many of these instruments or components are installed in the aircraft (2). Some components are installed multiple times in the case that the primary component fails. When the primary component fails, the pilot needs to grab the MMEL and check if the flight operation is in danger without that component. The MMEL contains namely an extra section which tells the pilot how many of the components are needed to operate safely (3). The MMEL’s last section is about the remarks or the exceptions in which the aircraft may fly even if the component fails and there is not a backup component (4).

<table>
<thead>
<tr>
<th>SYSTEM &amp; SEQUENCE NUMBER</th>
<th>ITEM</th>
<th>1. NUMBER INSTALLED</th>
<th>2. NUMBER REQUIRED FOR DISPATCH</th>
<th>3. REMARKS OR EXCEPTIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>32 - LANDING GEAR</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Gear Seal Warning System (-100/-200)</td>
<td>C</td>
<td>1</td>
<td>0</td>
<td>(M) May be inoperative provided gear seal function is checked once each flight day.</td>
</tr>
<tr>
<td>2. Antiskid System</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1) (-100/-200/-300/-400/-500)</td>
<td>C</td>
<td>1</td>
<td>0</td>
<td>(O) May be inoperative provided operations are conducted in compliance with AFM.</td>
</tr>
</tbody>
</table>
| 2) (-600/-700/-800/-900)   | C   | 1 | 0 | (M) May be inoperative provided:  
  a) Associated Antiskid channel(s) is deactivated, and  
  b) Operations are conducted in compliance with AFM. |

Legend:  
1. Component  
2. Numbers installed  
3. Numbers required for dispatch  
4. Remarks or exceptions
2. Mechanical analysis
Whenever an aircraft lands or takes off different forces act on the aircraft. In order to give a better overview about these forces on an aircraft a free body diagram will be made. A free body diagram shows every force on an aircraft, these forces can be calculated with basic formulas and mechanical principles (2.1). A landing gear is specially designed to withstand these different forces. The landing gear is made from specially selected materials which need to be strong, durable and heat resistant (2.2). All forces differ from each other because in every situation the conditions change. Four types of phases will be analyzed: when the aircraft is in static situation, taxiing, making a rejected take-off and landing (2.3). The forces which act on the aircraft act on three different components of the landing gear. These are the shock strut, the wheel axes and the side strut. The forces which work on these components are different from the force on the total landing gear. The force is called the shear stress (2.4). In the conclusion it is acknowledged which material is the best to use in the landing gear assembly (2.5).

2.1. Basic theory mechanics, free body diagrams and geometry
There are many different ways of testing the forces acting on an aircraft. The practical way is to measure the force on the aircraft or a part of it by simulating the situation. The theoretical way is by calculating the forces on the aircraft (2.1.1). The landing gear needs to withstand all the forces and moments. The size of forces and moments on the aircraft is dependent on the situation the aircraft remains in. A free body diagram is made to give a clear overview of the forces which work on an aircraft (2.1.2).

2.1.1. Basic theory mechanics
Formulas are needed in order to calculate the force on a part of the aircraft. The formula which is used to calculate the thrust force is the second law of Newton (2.1.1a). In order to calculate the normal force of the aircraft basic principles of mechanics are needed (2.1.1b). When the aircraft moves forward over the ground the wheels of the aircraft experience friction, this friction can be calculated using the friction formula (2.1.1c). When a force is applied to the landing gear it experiences stress in its structure, this stress is calculated with the shear stress formula (2.1.1d).

2.1.1.a Newton’s second law
An object which is in motion, has a constant speed or is accelerating. Newton discovered that the force of the object during the movement has a relation between the mass of the object and its speed. After many deductions Newton came up with a common formula which explained the force (formula 2). The object’s mass multiplied by its acceleration results in the force which the object produced.

\[ F = m \times a \]

\(F\) = force (N)
\(m\) = mass (kg)
\(a\) = acceleration (m/s\(^2\))

Formula 2     Second law of Newton

2.1.1.b Basic principles of mechanics
When a force is applied on an object in a static situation, a reacting force in the opposite direction needs to be so that forces always are in balance. This is one of the basic principles of mechanics (formula 3). The force which is applied to that object also creates a moment around the object. For example when a force is applied perpendicular to the top of a building, the force wants to push over the building. Thanks to the basic principles a reacting force needs to keep the building in place. In this case it is the fundament of the building which keeps it standing. The basic principles in a formula are: when a force is applied on the object a reacting force will keep it in balance. This also applies for the moments.

\[ \sum F_x = 0 \quad \sum F_y = 0 \quad \sum M_{xy} = 0 \]

\(F\) = force (N)
\(M\) = moment (N-m)

Formula 3     Basic principle of mechanics
2.1.1.c Drag formula
When the aircraft is moving on the ground the wheels experience friction. This friction depends on the normal force. This force keeps the aircraft on the ground, so the aircraft is pulled towards the ground which is a factor that causes the friction. The normal force is not the only reason why the aircraft is experiencing friction. The rubbers of the wheels in combination with the asphalt also play a role in the friction formula (formula 4). These factors ensure the aircraft has grip on the ground, without the grip the aircraft would not be able to move forward.

\[ F_{WR} = \mu \times N \]
\[ \mu = \text{friction coefficient} \]
\[ N = \text{normal force (N)} \]
\[ F_{WR} = \text{friction (N)} \]

Formula 4  Friction formula

2.1.1.d Constructional stress
The landing gear experiences a huge amount of forces when the aircraft performs a rejected take-off or when the aircraft lands. The landing gear needs to carry the full mass of the aircraft in its struts. These struts experience a pressure, which is called stress (formula 5). In order to calculate the stress in the strut, the dimensions of the strut need to be known. The stress is the amount of force which is applied to the strut per unit area. The area of the strut’s cross-cut is of vital importance for the formula. So the stress depends on the applied force and the area.

\[ \sigma = \frac{F}{A} \]
\[ F = \text{force (N)} \]
\[ A = \text{area (m}^2) \]
\[ \sigma = \text{shear stress (MPa)} \]

Formula 5  shear stress

2.1.2. Free body diagrams
An aircraft needs to withstand every force it experiences during every ground move. There are three ground movements in which the force on the landing gear are greater than in the static situation. In order to calculate every force on the aircraft, free-body diagrams need to be drawn (appendix XXVII). These diagrams show every force on an aircraft using vectors. During the static situation the aircraft experiences several forces (2.1.2a). When the aircraft is ready to take-off, it needs to taxi to the runway (2.1.2b). After the taxi the aircraft is ready to start its takeoff. When a malfunction occurs during the take-off, the pilot needs to perform a rejected takeoff (2.1.2c). Also, when the aircraft touches down, several forces are applied on the landing gear (2.1.2d).

2.1.2.a  Static situation
When the aircraft is fully loaded and the air traffic control (ATC) gives a signal that the aircraft needs to wait before it can taxi to the runway it already experiences several forces. The weight of the aircraft wants to push the aircraft into the ground, this is because of the gravity. As already mentioned, every force needs a reacting force in the reverse direction: the normal force. The nose landing gear and the main landing gear experience these forces in different proportions.

2.1.2.b  Taxi
The ATC gives the pilot a signal that it is clear to taxi. When the aircraft starts to taxi, the aircraft engines needs to deliver a small amount of thrust to move forward. The aircraft needs to move during the taxi with a constant speed. The force applied in static situation are still working on the aircraft during the taxi. Next to the normal and the gravitational force the aircraft experiences new forces. The wheels deliver grip, this grip needs to be there in order to move but it also delivers drag.
2.1.2.c  Rejected take-off
When the pilots decide to perform a rejected take-off, the forces on the landing gear are the greatest. The aircraft accelerates towards V1 (the velocity where the pilots are able to decide whether to continue the take-off). In order to stop the aircraft, the brakes are fully deployed and the reverse thrust is activated. These two forces should balance the forward force.

2.1.2.d  Landing
The ATC gives permission to land. The landing gear needs to absorb the great impact of the body landing on its main landing gear. The weight, which was divided over the nose landing gear and the main landing gear, needs to be fully absorbed by the main landing gear. The forward force needs to be balanced by the brakes, reverse thrust and the speeds brakes.

2.2.  Design and materials
When the landing gear is extended or retracted a simple mechanical principal, called four-bar linkage, is used. The four-bar linkage system of the Boeing 737-800 NG shows that the landing gear is connected to the aircraft at two different places. Knowing how these points are attached to the aircraft helps the mechanics in order to calculate the forces and moments at the junction (2.2.1). Different types of materials have different kind of characteristics. It is useful to know which material can withstand the high forces of the landing gear (2.2.2).

2.2.1. Design
The four-bar linkage is a very simple but very effective mechanical construction. It consist of four bars (two of them are connected to a fixated item) that are connected to each other in such a way that they can make different movements (appendix XXVIII):

1. Drag-link
2. Crank rocker
3. Double rocker
4. Parallelogram linkage

ad1 Drag-link
This is a type of linkage that can make various types of movements. The loose points of the linkage can move in large circles around the fixated points. This type of linkage has the possibility to react the same as an double rocker or as the parallelogram linkage.

ad2 Crank rocker
This linkage uses one bar that continuously moves in a circular motion. This causes the other bar to go up and down. This type of linkage is often used in a pump jack because of the up and down effect that is needed to gain oil.

ad3 Double rocker
Unlike the other types of linkages, this linkage is not continuous. This means that the movement can go on in the same direction for ever. It has to stop and go back to do the same move again. It cannot continue to move when the limit of the construction is reached. When it is reached the mechanical linkage, has to return to the other outer limit in the construction. It shows that the two larger bars move in a relatively small motion.

ad4 Parallelogram linkage
This type causes the two shorter bars to rotate simultaneously. The non-fixated larger bar stays horizontal in every configuration of the smaller bars. This happens because the smaller bars always have the exact same position in relation to each other.

The landing gear of a Boeing 737-800 NG uses a four-bar linkage similar to the drag link. The fixated bar of the four-bar linkage is the aircrafts fuselage. Both the nose landing gear and the main landing gear use the same
principal when retracting (appendix XXIX). The shock strut and the side strut of the main landing gear are attached to the aircraft by the use of a bolt. This enables the main landing gear to pivot around the top of the shock strut to retract or extend. The nose landing gear is attached to the aircraft by using the same principal as the main landing gear.

2.2.2. Materials
The landing gear consists out of several materials. Almost all parts need be able to handle a lot of forces and even some parts need to withstand high heat. The weight of the material can be a disadvantage. So the parts of a landing gear consist out of steel (2.2.2a), titanium (2.2.2b) and aluminum (2.2.2c). Mostly, these materials, when used in aircraft, are alloyed. This is made when two materials are put together in a solid form. This is to improve the properties and to strengthen the structure of the material. For example, titanium needs most of the time another material to improve its heat resistance, so the material does not melt at a higher temperature. Next to metals it is also possible to put a material, such as carbon fiber, together with aluminum. This is called composites (2.2.2d).

2.2.2.a Steel
Steel is an alloy of iron and carbon. The carbon is used to get a high tensile strength and hardness. So the more carbon is added how harder the steel becomes. It is not possible to add carbon infinitely. There is a proportion for the amount of carbon against iron. Until the materials are saturated. The advantage of steel is the material is very strong and is relative cheap. A disadvantage is that steel is quite heavy.

2.2.2.b Titanium
It is very hard to find titanium in its pure form. Titanium has a lot of advantages: it is strong, light and corrosion prove. Titanium alloys are often used in aircrafts because the material is resistant against high temperature and titanium is as strong as steel. Titanium is often used in combination with aluminum, vanadium, molybdenum or chrome. When the titanium is an alloy with one of these materials the properties are changed. The change of the material only happens when the two materials are mixed together at a high temperature. During this process the materials has different influence on each other. For example, the material is now less brittle and more flexible.

2.2.2.c Aluminum
Aluminum has the advantage that the material is light (1/3 of the weight steel), flexible and retains his shape, electric conductive and corrosion free. The material is quite easy to shape and aluminum is easy to process. Pure aluminum is rare, but the material bauxite that consists out of Al₂O₃ is used to get aluminum. The only way aluminum can get his strength is to combine it with another material, like magnesium.

2.2.2.d Composite material
Composite materials are two or more materials which are mixed together to get the correct material properties. In an aircraft a lot of aluminum with glass fiber mixed is used, this gives glass reinforced aluminum also called “glare“. Glare is a mix of aluminum and glass fiber, these two materials are together very strong, about one and a half times stronger than steel. The fiber in the composite material takes care of the forces letting trough. This is to change the shear stress to a bigger area.

2.3. Forces and moments
In situations during different ground movements, the landing gear structure must bear the aircraft fuselage, thus the whole aircraft weight. Forces and moments act on the aircraft and on the landing gear. These forces are transmitted to the aircraft fuselage. Due to the elastic deformation of the aircraft fuselage the acting forces are partly absorbed (appendix XXX). To determine the ground movement with the maximal forces on the landing gear, different ground movements are analyzed. Taxiing with a constant velocity generates reaction forces that are balanced (2.3.1). The forces on the landing gear during a rejected take-off are more critical; the energy generated by the aircraft velocity is converted to heat in the brakes (2.3.2). The landing gear captures the landing
pulse and converts the energy to heating. Then, the landing gear must cope with the forces generated on the landing gear structure (2.3.3).

### 2.3.1. Taxi

To analyze the taxi situation, taxiing with a constant taxi-velocity of 10.3 m/s (maximum taxi speed set by regulations) is used. The landing gear wheels contact the ground and have to do with friction. The kinematic friction coefficient ($\mu$) displays the amount of friction between the wheels and the surface (formula 4). In this free roll situation the friction coefficient is 0.2 ($\mu=0.2$). The product of the friction coefficient and the normal force acting on each landing gear ($N_A$ en $N_B$) gives the total friction. Using the given equations it makes possible to calculate all acting forces on the landing gear during taxi (appendix XXXI).

The following numbers are needed in order to calculate the landing gear forces during taxi:

- $\mu = 0.2$
- $N_A = 116272.05$ N
- $N_B = 658874.95$ N

Consequently, it is possible to calculate the landing gear forces during taxi:

1. $F_{W,A} = \mu \cdot N \Rightarrow F_{W,A} = 0.02 \cdot 116272.05 = 2325.4$ N
2. $F_{W,B} = \mu \cdot N \Rightarrow F_{W,B} = 0.02 \cdot 658874.95 = 13177.5$ N
3. $F_{\text{thrust}} = F_{W,A} + F_{W,B} \Rightarrow F_{\text{thrust}} = 2325.4 + 13177.5 = 15502.9$ N
4. $W = 775147$ N

As given that the aircraft moves with a constant velocity, the sum of all forces is zero. That means the sum of the forces in all directions and the sum of the moments is zero.

### 2.3.2. Rejected take-off

A rejected take-off is a situation where in an aircraft aborts the take-off below or at V1 which depends on the type of aircraft, the weight of the aircraft and weather circumstances. Before each flight, this speed is calculated. When an aircraft aborts its take-off above V1, the aircraft may overrun the runway.

During a rejected take-off, more forces are produced on the nose landing gear than during other ground movements. These forces depend on the circumstances during a rejected take-off, such as the weight and the condition of the runway. To calculate the maximum forces on the landing gear of the Boeing 737-800 NG during a rejected take-off, the maximum take-off weight (MTOW) of 79,016 kg is used. For this weight, a V1 speed of 144 kts is known and a deceleration rate of 3.4 m/s$^2$. Assuming that there is no lift and no drag during the whole process, we can calculate the force that is needed to decelerate the aircraft with the known deceleration rate. The applied deceleration is done by only the brakes during the rejected take-off, so no reverse thrust is taken into account. The brake force that is needed to decelerate the aircraft with 3.4 m/s$^2$ can be calculated with Newton's second law:

$$F_{\text{total}} = 79016 \cdot 3.4 = 268654.4 \text{ N} \quad \text{Answer}$$

The brake force is produced by four brake units on the four wheels of the main landing gear. So per main landing gear a brake force of 134327.2N is produced. The distance of the CG to the center of the main landing gear wheel is 4m and to the nose landing gear is 13.26m. The moment that occurs around the CG during the rejected take-off is zero, so now the forces in the nose landing gear can be calculated (formula 3):

$\Rightarrow +M_{CG} = 4 \cdot F_{\text{brake}} + 2.34 \cdot 0.85 \cdot 9.81 \cdot 13.26 - 13.26 \cdot F_{N\text{ NLG}} = 0$

$\Rightarrow +M_{CG} = 4 \cdot 268654.4 + 2.34 \cdot 0.85 \cdot 9.81 \cdot 79016 - 13.26 \cdot 13.26 \cdot F_{N\text{ NLG}} = 0$

$$F_{N\text{ NLG}} = \frac{2616384.9}{13.26^2} = 197314.1 \text{ N} \quad \text{Answer}$$
During a static situation it is known that the normal force on the nose landing gear is 116,272 N. So during rejected take-off, 81,042.1 N (197314.1 N - 81 042.1 N) more will be applied on the nose landing gear.

2.3.3. Landing

The forces on the main landing gear are calculated according to a certain situation. The adopted situation will be a rough landing on a concrete runway. The lift component will not be taken into account, so that the maximum weight can be calculated on the main landing gear. The weight will only be on the main landing gear with maximum take-off weight and a vertical landing speed of 3.05 m/s.

If the total mass of the aircraft is descending with a vertical landing speed of 3.05 m/s and the main landing gear struts are deflected 0.406 m, the time it took to deflect can be calculated. The first step is that the average speed has to be calculated. The descending rate is 3.05 m/s and the vertical speed rate is considered to be 0 m/s. Calculated, the average speed will be 1.525 m/s. To calculate the time of deceleration, the deflection has to be divided by the average speed which is $\frac{0.406 \text{ m}}{1.525 \text{ m/s}} = 0.266 \text{ s}$.

To determine the rate of acceleration, the rearranged distance formula will be used. By substituting all the known variables, the acceleration rate can be determined.

The last step is calculating the force on the main the landing gear. The basic force formula can be used. By substituting the known variables the force can be determined.

The following numbers are needed in order to calculate the landing gear forces during taxi:

- The main landing weight of the aircraft: 65,320 kg
- Descent rate: 3.05 m/s
- Main landing gear shock strut deflection: 0.406 m

Consequently, it is possible to calculate the rate of acceleration (formula 2):

1. $F = m \cdot a$
2. After derivation, the actual formula becomes:
\[
\sum_{s_1}^{s_2} F \, ds = \sum_{v_1}^{v_2} (m \cdot v) \, dv
\]
3. $\sum F \cdot (s_2 - s_1) = 0.5m \cdot v_2^2 + 0.5 \cdot v_1^2$
4. $\sum F \cdot (0.406) = 0.5 \cdot 65320 \cdot (0)^2 + 0.5 \cdot 65320 \cdot (3.05)^2$
5. $\sum F \cdot 0.406 = 303819.65$
6. $\sum F = 748324.26 \text{ N}$

Answer

2.4. Constructional stress

Forces are placed on the landing gear in nearly all ground movements. The forces acting on the landing gear are mentioned in section 2.2. However, these forces are external forces: it is the actual force distribution across the area of the section. But forces are also acting inside the area of the section. We call such a force stress (2.4.1). There are several parts in the landing gear assembly that are more vulnerable to stress than other parts, also called the critical parts. Calculations must indicate the stress in those critical parts (2.4.2).

2.4.1. Stress

As already mentioned in the introduction of this section, stress is a force acting on an area of an element (figure 20). In other words: it is the density of the inside force on a particular area through a point. On every area $\Delta A$ of such an element, a force $\Delta F$ is acting. When this area is reduced to the minimum, the resultant force will also be reduced to the minimum (1). $\Delta F$ can be substituted in three forces in x-, y- and z-direction (2).

It is assumed that the materials of the parts in the landing gear are continuous (without empty spaces) and coherent (without any cracks, splits and gaps).
2.1. Legend:
1. Very small force $\Delta F$ working on a very small area $\Delta A$.
2. The resultant force can be substituted in three forces in x-, y- and z-direction.

Figure 20 Stress working on an element

Stress can be subdivided in two types:
1. Normal stress: the force acting on an area, which acts perpendicularly on $\Delta A$. The formula (formula 6):

$$\sigma = \frac{N}{A}$$

$\sigma =$ normal stress (mega Pascal (MPa))
$N =$ normal force (N)
$A =$ area ($m^2$)

Formula 6 Normal stress

2. Shear stress: the intensity of the force, or the force per square meter, which touches $\Delta A$ (formula 7).

$$\tau = \frac{V}{A}$$

$\tau =$ shear stress (MPa)
$V =$ shear force (V-force) (N)
$A =$ area ($m^2$)

Formula 7 Shear stress

2.4.2. Stress calculations on the critical parts
During a static situation, taxi, take-off and landing, there are forces placed on the landing gear. Some parts of the landing gear assembly are forced more than other parts. For instance, some parts regulate the retraction and extension mechanism and other parts absorb the energy during landing. These critical parts need to be taken into consideration. Three parts will be calculated on stress: the shock strut (2.4.2a), the side strut (2.4.2b) and the wheel axes (2.4.2c).

2.4.2.a Shock strut
The shock strut is the most critical part of the landing gear: it must absorb the maximum landing weight (MLW) of 65317 kg (appendix XXXII). To calculate the stress in one main landing gear strut (of the two), it is necessary to divide the weight in two (acting on these shock struts). In order to calculate the force on the shock strut, this weight must be multiplied with the gravitational constant of 9,81 m/s$^2$ (formula 8). The area of a circle (the shock strut is a cylinder) can also be calculated by an equation (formula 9). Its diameter is 213,4 mm.

Thus, the normal stress equation can be applied. The result is 8,96 MPa.

$$F = m \cdot g$$

$F =$ force (N)
$m =$ MLW (kg)
$g =$ gravitational constant (m/s$^2$)

Formula 8 Normal force on the shock strut

$$A = \pi \cdot r^2$$

$A =$ area ($mm^2$)
$\pi =$ pi (3,14)
$r =$ radius (mm)

Formula 9 Area of a circle
2.4.2.b Side strut
There are no forces acting on the side strut of the main landing gear during a perfect landing (appendix XXXIII). Only with crosswind factors and during taxi turns, there are forces placed on the side strut. The side strut has its primary use to extend and retract the main landing gear.

2.4.2.c Wheel axes
During the landing, forces will be placed on the wheels and tires. The axes of these wheels will absorb a part of the landing energy. If one cuts an axis, the weight force will act as a shear stress (appendix XXXIV). Next, if the diameter of an axis is known, it is possible to calculate the shear stress, because there will no normal force act on the wheel axis. It needs to be taken in consideration that there are two axes on one main landing gear assembly (with a total of four). So the V-force must be divided in 4. Then the area of a wheel axis can be calculated (formula 9) and then the shear stress (formula 7). Thus, the shear stress is 2.04 MPa.

2.5. Conclusion
In this chapter the landing gear of the Boeing 737-800 NG was analyzed. The things that were looked at are the design, materials and forces on the landing gear during several ground movements. The purpose was to calculate which phase causes the most stress on the landing gear and what kind of materials and designs were used to make the landing gear as durable as possible. The landing gear design of the Boeing 737 is a four-bar linkage which is used on the nose and main landing gear. This is a very efficient way to extend and retract the main landing gear. The materials used on the Boeing 737-800 NG are carefully chosen based on advantages and disadvantages. Keeping the advantages and disadvantages in mind steel, aluminum, titanium and composite materials are the materials that are used in the landing gear. After knowing now what the design and what the materials are, the different situations that cause stress on the landing gear can be calculated. Such as a static situation, taxiing, rejected take-off and landing were calculated. After calculating all situations accurately the rejected take-off has proven to be the situation which causes the most stress on the landing gear. With this information, the problems in the last chapter can be analyzed more thoroughly.
3. Operational analysis

In order to improve the maintenance plan of ALA, it is necessary to analyze the influence on the airworthiness of the aircraft by describing two malfunctions that could occur in the landing gear assembly. Also a financial analysis must be made to give an overview of the consequences of these two malfunctions. To gain an insight into the maintenance plan of ALA to improve, it is sensible to describe Boeing’s current maintenance plan, in which is explained what procedures need to be performed by order of Boeing (3.1). Subsequently, a hydraulic failure (malfunction 1) in the aircraft’s hydraulic system could cause an improper functioning of the landing gear. The solution is an automatically switch between hydraulic system A and B. To prevent this malfunction in the future, maintenance must be performed as much as possible during the checks (3.2). A wheel failure (malfunction 2) could cause flat tires, especially during a rejected take-off. When the pressure gets too high in the tire, pressure relief valves must release a part of the nitrogen in the tire, so it will not burst. If the pressure relief valve cannot handle all over temperature, the fuse plugs will melt and the tire will completely deflate. When these pressure relief valves do not work properly, the tire will become deflated. To prevent this malfunction, often performing maintenance and checks are important (3.3). A change in the financial situation occurs, because these malfunctions will cost ALA more money. However, benefits are created also (3.4). A conclusion will give the board of ALA a recommendation on the maintenance policy (3.5).

3.1. Current maintenance plan

During all ground movements, the aircraft rests on its landing gear, which makes maintenance necessary. The current maintenance that is done on an aircraft can be divided in two types. The first type is called scheduled maintenance. This consists out of the daily checks, A-, C- and D-checks (3.1.1). The second type is the unscheduled maintenance. This only happens when a failure occurs during normal operation (3.1.2).

3.1.1. Scheduled maintenance

The scheduled maintenance can be divided in:

- Daily check
- A-check
- C-check
- D-check

**ad1 Daily check**

A daily check is done before every flight or every 24 hours. The check consists out of engineers inspecting all the critical parts of the landing gear to find signs of damage or wear. The engineers do a visual inspection of the main landing gear brake assembly and wear indicators, they also check the main landing gear tire pressure and do a visual inspection of the main landing gear wheels and tires. The failure record is also checked by the engineers. For this check no specific equipment needs to be used.

**ad2 A-check**

This check is done every 850 flight hours or every three months. This check can be done at the gate, however, special equipment is needed. During this check, several components of the landing gear are checked. A few of these are brake wear inspection, wheel replacement, visual inspection of retraction actuators, visual inspections of up lock actuators, lubrication of landing gear, checks of fluid/gas levels and greasing of hinges. This check takes about 24 hours.

**ad3 C-check**

This check is done every eighteen months. It is done at the maintenance base and consists of a detailed visual check of specific parts and systems and operational checks. Checks such as functional check of landing gear selector valve and main landing gear torque links. It is very wide ranging and it takes about three to five days.
This check is done after the first 96 months of aircraft service. The second one is done after 72 months and the every time after 60 months. This is the most intensive check. Every part of the aircraft is dismantled and sent to the manufacturer for a significant check. The drag strut assembly and shock strut assembly are completely substituted. This check takes about four weeks.

3.1.2. Unscheduled maintenance
This type of maintenance occurs unplanned for example in case of a bird strike, rejected take-off or in case the engineer finds signs of wear or damage during the daily check. In this case maintenance will have to be done unscheduled. The duration of maintenance depends on how severe the problem is.

3.2. Hydraulic failure
One of the most common failures in aviation is a hydraulic failure. There are different kinds of failures in the hydraulic system. The hydraulic failures that are going to be explained are temperature, negligent maintenance and cavitation problems (3.2.1). When failures and problems occur, the airline needs to know what the influence is on the airworthiness (3.2.2). Only then, the pilot can consider if he resumes the flight or needs to land immediately. When the pilot decides to resume, it is necessary to know how the problem or failure can be solved (3.2.3). The maintenance crew needs to know how the problem can be avoided (3.2.4).

3.2.1. Failures
Hydraulic systems need various conditions in order to work. These conditions are the temperature, the hydraulic fluid and the attention of the maintenance crew. Each of these factors are important for safe operations. Failures in the hydraulic system can occur because of different reasons:
1. Over temperature
2. Negligent maintenance
3. Wear

3.2.1.1. Over temperature
When the temperature in the hydraulic system is too high, the viscosity of the hydraulic fluid will decrease. When the viscosity of the hydraulic fluid decreases, the fluid cannot fulfill its purpose. One of the main purposes of the hydraulic fluid is the lubrication of the hydraulic system. If the system cannot be lubricated, the system could jam. If this occurs and the system jams, it cannot fulfill this purpose, which is actuating the larger components of an aircraft. One of these larger components is the landing gear.

3.2.1.2. Negligent maintenance
When an airline needs to reduce their expenses they reduce on maintenance. The EASA has defined how many hours an aircraft may fly before it needs to be checked. In this definition there is a minimum and a maximum amount of flight hours defined. The minimum is when the aircraft could be checked and the maximum is when the aircraft must be checked. If the airline wants to reduce its expenses, it lets the aircraft fly until the maximum is reached. This can turn out very bad, because most of the time the hydraulic fluid needs to be renewed during this time. If the airline manager decides to fly until its maximum flight hours before a check, he will discover that the hydraulic system can be damaged by this decision.

3.2.1.3. Wear
Hydraulic fluid flows under a huge amount of pressure. This combination of flowing and the huge amount of pressure can create a turbulent current. When the temperature drops, inside the hydraulic fluid little bubbles arise. These bubbles can become bigger when the bubbles enter an area with a low pressure. If the bubbles travel from a low pressure area to a high pressure area, the bubbles implode. This creates a shockwave in the hydraulic pipelines which could damage the system. One of the consequences is the pollution of the hydraulic fluid. This pollution consists out of small metal particles. When this happens, too many times the filter can become clogged,
causing an under pressure in the hydraulic system, due to the under pressure the system cannot actuate the main components of the aircraft.

3.2.2. Influence airworthiness

In the MMEL is described which systems are necessary in the aircraft. In this MMEL it is indicated that only the system pressure indication (system A and B), system A and B pump low pressure in the indication system, hydraulic reservoir pressurization system sources and the system B pump are necessary to fly. These systems are only count for the hydraulic system (appendix XXVI). When one of these systems is not operating correctly, the aircraft is not able to fly or needs to land immediately and needs to be checked. But when the landing gear is not operating correctly, it cannot extend. The second pressure system can solve the problem or the landing gear needs to be extended manual. When the pilot needs to extend the landing gear manually, the only thing the pilot needs to consider is the time it takes to extend the landing gear.

3.2.3. Solutions

To ensure that the landing gear can be extended, there are two solutions. The first one is, when there is a under pressure in hydraulic system A, the pilot gets a warning that the system is not operating correctly. Automatically, hydraulic system B takes over the functions of system A. The problem needs to be reported to the maintenance crew of the airline. The crew will conduct a research about the possible cause of the problem and research if the malfunction may could have been prevented. The other solution is only available when hydraulic system A and B are not working correctly. Then there is a bigger problem, because there is no hydraulic system which can extend the landing gear hydraulically. Now the landing gear has to be extended manually. To unlock the landing gear there is a hatch in the floor which contains the floor handles. When the pilot pulls on these handles, the gear unlocks and extend due to gravity. When an under pressure appears in hydraulic system A and B, the pilot need to land as soon as possible. The problem needs to be reported to the maintenance crew of the airline.

3.2.4. Prevention

When airlines need to reduce their expenses, they usually try to save money on maintenance. This is not clever, because the hydraulic system of an aircraft needs to be checked for faults. To prevent a hydraulic failure, one of the solutions is to compromise. Airlines reduce their expenses and make profit. Also, the aircraft authorities demand that the aircraft operations are performed as safe as possible. The maintenance check will be done after the aircraft is between the maximum and the minimum number of flight hours, so the check will be done after 650 flight hours.

3.3. Wheel failure

The tires could explode due to heavy braking (3.3.1). This has a negative effect on the operations of the aircraft (3.3.2). The solution of this type of wheel failure is done by the use of thermal fuse plugs (3.3.3). To prevent a malfunction of the fuse plugs, they need to be checked periodically (3.3.4).

3.3.1. Failure

The pilot applies full brake when the aircraft makes an rejected take-off. When this happens, the friction in the brakes causes the forward kinetic energy to decrease. The kinetic energy is converted into heat by the brakes. The heat of the brakes has direct influence on the nitrogen in the tires. The pressure of the nitrogen increases rapidly due to the overheated brakes. Without any opening in the tires, which the nitrogen can use to escape into the atmosphere, the pressure increases to a point where the pressure is too high. Then, the tires will explode.

3.3.2. Influence airworthiness

Overheated breaks are a serious problem in aviation. In case of exploding tires, due to overheated brakes, the aircraft is not save to operate anymore. Also, there is no guarantee that a rejected take-off can be performed safely. The aircraft can still fly when the brakes are overheated. But when there is no guarantee that the aircraft
can perform an emergency brake, it is not safe to fly because braking happens during the landing phase. Therefore, if this malfunction occurs, the aircraft is not airworthy.

3.3.3. Solutions
The aircraft uses fuse plugs to prevent the tires from exploding (figure 8). Fuse plugs are plugs that melt when they reach a certain temperature. For the B737-800 the fuse plugs melt at approximately 380°F (193°C). The fuse plugs use the same principal as fuses in electrical systems. In electrical systems, the fuses cause the flow of electricity to stop. In the case of fuse plug an aircraft, which do not have to stop an electrical flow, the plugs are made to open and let the air inside the tires relief constantly. However, when the fuse plugs are melted, they cannot seal themselves again. The negative effect of this type of solution is that the aircraft cannot taxi until the fuse plugs are replaced and the tires are inflated again. The positive effect of this solution is that the tires cannot explode because the air inside the tires is relieved. Another solution of preventing exploding tires is the use of pressure relief valves. These valves open when the pressure reaches a certain point. The difference with the fuse plugs is that the pressure relief valves close when the pressure inside the tires reach the normal pressure in the tires. The positive effect is that the valves do not deflate the tires fully. Therefore, the aircraft can still function normally. The negative effect is that the valve cannot handle the rapid increase in pressure in case of an rejected take-off. That is why the fuse plugs are installed on the aircraft.

3.3.4. Prevention
To prevent the aircraft from making a rejected take-off, which could lead to overheated breaks, maintenance must be performed securely. The fuse plugs could have a problem when they are needed if the maintenance is not done correctly. For instance, not melting when needed. Therefore the best prevention is to check the fuse plugs before every take off and during every maintenance check. The same prevention can be used for the pressure relief valves. This ensures the pilots and technicians that the fuse plugs work properly.

3.4. Financial analysis
The current maintenance plan must provide enough protection for safe aircraft operations. The two malfunctions that were mentioned before, directly affect the aircraft’s airworthiness, if these malfunctions are not repaired. Critical parts of the landing gear were described, respectively one of the hydraulic systems and one or more wheels. These malfunctions must be resolved before departure, which brings along high costs (3.4.1). These malfunctions must be prevented as much as possible. When using more sustainable materials and doing more accurate checks, the current maintenance costs can be reduced (3.4.2).

3.4.1. Malfunction costs
The malfunctions in the landing gear that were described need to be solved and repaired before departure. Therefore, different types of costs come into existence. The materials needed for the repair must be present (3.4.1a). The damaged system components are replaced by maintenance personal. The fact that the aircraft cannot depart brings along costs too (3.4.1b).

3.4.1.a Materials costs
When malfunctions are repaired, different materials are needed. The two described malfunctions that may occur in the landing gear system are:

1. Hydraulic failure
2. Wheel failure

ad1 Hydraulic failure
When the described hydraulic malfunctions occur, the hydraulic fluid or the filters in the hydraulic system are replaced. Due to negligent maintenance of the hydraulic system, other components could be damaged too, for example the hydraulic pipelines.
ad2  Wheel failure

When a wheel failure occurs due to fuse plug failure, the tires could explode and need to be replaced. When the tires come off the axis, the wheel axis can be damaged too. After the fuse plugs are melted once, they must be replaced.

3.4.1.b Aircraft related operational costs

Nowadays airlines have to do with aircraft-related operating costs (AROC). These costs consist of six categories: flight and cabin crews, fuel, maintenance, navigation and landing fees, ownership and spares and depreciation (figure 21). Concerning the landing gear malfunctions and the current maintenance, the category ‘maintenance’ is of importance. The percentages are averages, but they are a representative reflection of the true situation. The AROC costs can be subdivided in three categories: direct airframe, direct engine and direct overhead. The landing gear maintenance belongs to the direct airframe maintenance which is approximately 4.5 percent of the total AROC costs.

The current maintenance plan states that the landing gear system is checked during respectively the A-, B-, C- and D-check, dependent on the landing gear component. Even after regularly checks, malfunctions can occur in the landing gear system. These malfunctions are solved during unscheduled maintenance. Due to the extra unscheduled maintenance, the operational costs increase incredibly. Then, the aircraft cannot depart and is delayed; the Aircraft on Ground costs (AOG) increase, the maintenance personal costs money and in case of large delays the passengers have to be paid back too.

Figure 21  Aircraft-related operating costs (AROC)

3.4.2. Benefits

When using more durable materials or preventing the occurrence of malfunctions, the material costs can be reduced (3.4.2a). At the same time, when there is more invested in prevention of malfunctions, the operational costs reduce too (3.4.2b).

3.4.2.a Material benefits

When saving on materials, the airworthiness of the aircraft may not be affected, because the aircraft must operate safe. The use of more durable or cheaper materials is not an option. More durable materials often bring along more cost and an increase of weight, which is negative for the aircraft operation possibilities. Besides, the use of cheaper materials causes even more possibility on malfunctions, because cheaper materials are often less durable. The material costs only decrease when the frequency of unscheduled maintenance reduces. The used materials are the same then, but the amount of materials will decrease because of less malfunctions.
3.4.2. b Aircraft related operational benefits

When the amount of maintenance hours is reduced, the AROC maintenance cost can be reduced and the percentage of direct airframe maintenance decreases. When more preventive maintenance is done during the normal maintenance checks, unscheduled maintenance is prevented as much as possible then (appendix XXXV). The critical parts of the hydraulic system and the wheels could be checked before each take off, whereby malfunctions in these components are lessens. The main critical parts of the hydraulic system are the filters, that clean the hydraulic fluid. The critical parts of the wheels are the fuse plugs. The other landing gear system components are maintained during the checks. The A-check could take place between the maximum and the minimum number of flight hours for which the A-check must be done. That means the check will be done after 650 flight hours. The more preventive maintenance of the landing gear during checks most likely reduces the occurrence of malfunctions and has an advantageous effect on the operational costs.

3.5. Conclusion

The landing gear of a Boeing 737-800 NG is a complex assembly. Its main purposes are providing the aircraft movement on the ground and absorbing the landing shock. It consists out of many (sub)systems for a proper and safe operation. Safety is one of the most important factors in aviation. The landing gear provides this safety on the ground and during the landing. To regulate this, EASA forms rules. When an aircraft is proved to be airworthy, it is allowed to perform passenger flights.

In order to perform safe flights, it is necessary to perform calculations on the Boeing 737-800 NG’s landing gear forces. During all ground movements, the landing gear is loaded with several forces. These forces must be balanced, otherwise it will collapse. The critical parts in the landing gear assembly must contain materials which are able to withstand these forces. Moreover, the construction method which is applied in the landing gear is of even more vital importance: it must block the landing gear from a collapse. The magnitude of the stress in the construction must not be too high. This is because on every little area of a critical part, a force causes a stress, which tests the critical parts (especially during landing) to the maximum.

During extreme or special circumstances, the forces and stress could demand too much of the landing gear. This could cause damage to components and/or systems. One of the most common malfunctions is a failure in the hydraulic system, an overheating in the tires. When such a malfunction occurs, the aircraft needs to be checked on its airworthiness. The current maintenance plan must prevent these malfunctions. However, it depends on the airline which maintenance plan is used. So, it is important to adapt the current maintenance plans to new ones, to prevent such malfunctions in the future. A new outline of the costs will appear when adapting the maintenance plan, but ALA will gain some benefits: less maintenance costs in the future and more safety to perform flights.

The landing gear is one of the most checked and maintained assemblies in aircraft. The current maintenance plan is adapted to a new one, which leads to higher costs. However, ALA gains benefits by applying this new maintenance plan. Moreover, the most common malfunctions can be prevented and so flying with ALA could be structurally and significantly safer than with other airlines. Therefore, fleet expansion in the future is recommended, because more satisfied passengers, leads to more (returning) passengers. With more aircraft, ALA can expand its activities and meanwhile gain more seat occupancy. Eventually, this will lead to more revenue.
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### Appendix I  Landing gear configurations

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<tr>
<th>Configuration</th>
<th>Design</th>
<th>Aircraft</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional gear</td>
<td><img src="image1" alt="Conventional gear diagram" /></td>
<td>DC-3</td>
<td>Light weight, two main wheels, one small tail wheel with low drag.</td>
</tr>
<tr>
<td>Single main gear</td>
<td><img src="image2" alt="Single main gear diagram" /></td>
<td>U-2</td>
<td>Light weight, sensitive for crosswind, difficult maneuvering, outriggers under the wings.</td>
</tr>
<tr>
<td>Bicycle gear</td>
<td><img src="image3" alt="Bicycle gear diagram" /></td>
<td>B-47</td>
<td>Light weight, outriggers under the wings, unstable, position CG disadvantageous, rotating difficult.</td>
</tr>
</tbody>
</table>

**Conventional gear**

- Useful for light aircraft and piston-engine aircraft.
- Light weight, two main wheels, one small tail wheel with low drag.

**DC-3**

- Light weight, two main wheels, one small tail wheel with low drag.

**U-2**

- Light weight, sensitive for crosswind, difficult maneuvering, outriggers under the wings.

**B-47 Stratojet**

- Light weight, outriggers under the wings, unstable, position CG disadvantageous, rotating difficult.
Tricycle gear

Used in most commercial aircraft.

Stable design, easy steering, good visibility, nose view, large weight, easy to load, drag increase.

B737, B757
Airbus A320.

Quadricycle gear

Often used in cargo or bomber aircraft.

Almost similar to the bicycle gear, unstable, movable gear, close to the ground, easy to load, rotating difficult.

B-52

Multi-bogey gear

Used in big aircraft with large weights.

Multiple wheels on one bogey, two nose gears, tires spread large weight over the ground.

Boeing 747,
Boeing 777,
An-225.
Appendix II  Shock strut construction

Legend:
1. Inner cylinder
2. Outer cylinder
3. Gas charging valve
4. Oil charging valve
5. Walking beam
6. Walking beam hanger
7. Side strut
8. Reaction link
9. Connection to main gear up lock brackets
10. Torsion links
11. Shimmy damper
12. Jack pad
Appendix III  Location air/ground relays junction box

The air/ground relays are located near the nose landing gear. When the nose landing gear is in its down position the junctions boxes are easy accessible by the maintenance crew. Multiple junction boxes are needed to contain every air/ground relay an aircraft has.
Appendix IV  PSEU system 1

System one of the PSEU communicates with system 2. When these systems compare the variables of the sensors, they can activate the air/ground relays which actuate the components of several aircraft systems.

- AntiSkid/AutoBrake Control Unit (AMCU)
- Auto Speedbrake Control Module
- Flap/Slat Electronics Unit (FSEU)
- Stall Management Yaw Damper (CMYD)
- AC Indication
- Cabin Pressurization System
- RAMP AIR DOOR CONTROL
- ANTI-ICE
- PITCH HEAT
- Bus Power Control Unit (BPCU)
- Generator Control Unit (GCU)
- Auxiliary Power Unit (APU) START
- Auxiliary Power Unit (APU) WARNING
- Thrust Reversers System
- Common Display System (CDS)
- VHF Communications System
- HF Communications System
- Voice Recorder System
- Flight Data Recording System
- ACR Data/Inertial Reference System (ADIRS)
- Integrated Flight System Accessory Unit (IFSAU)
- Radio Altimeter System
- Weather Radar System
- Instrument Landing System (ILS)
- VHF Omnidirectional Ranging (VOR) System
- Marker Beacon System
- Distance Measuring Equipment (DME) System
- ACR Traffic Control (ATC) System
- Traffic Alert and Collision Avoidance System (TCAS)
- Ground Proximity Warning System (GPWS)
- Flight Management Computer System (FMCS)
- Digital Flight Control System (DFCS)
- AutoThrottle System
Appendix V  PSEU system 2

System two of the PSEU communicates with system one. When these systems have compared the variables of the sensors, they can activate the air/ground relays which actuate the components. The components that are being actuated by system two are different from the systems operated by PSEU system one.
Appendix VI       System 1: Air/ground relays

System one actuates many different relays of several aircraft systems. The relays which are actuated by system one are displayed.
Appendix VII  System 2: Air/ground relays

System two actuates many different types of relays. The relays which are actuated by system two are shown below.

![Diagram of air/ground relays]
Appendix VIII  Bias tire

The wire beads (1) are hoops of high tensile strenght steel wire which anchor the casing plies and provide a firm mounting surface on the wheels. On the side of the wire beads are the flippers (2), these layers of rubberized fabric help anchor the bead wires to the casing and improve the durability of the tire. The casing plies (3) are anchord by wrapping them around the wire beads, so they can form the plyturnups (4) which made the tire stronger. To minimize the chafing there are chafers (5). To prevent any nitrogen leaking, the tire need to fit exactly around the axis. The apex strip (6) is a wedge of rubber on top of the bead bundle. The bead toe (7) and the bead heel (8) are the inner bead edge and prevent leaking because it fits exactly against the wheel flange. The inside of the tire is also called the innerline (9), because in tubeless tires the inner layers acts as a built in tube and restrict the nitrogen from diffusing into the casing plies. On top of the tire there are also reinformcements called buff line cashion (10) and breakers/belts (11). These reinforcements provide an stabilized area and the tick layer of rubber is of sufficient thickness to allow for the removal of the old tread when the tire is retreaded. Tread (12) is made of rubber and compouned for toughness. This compound is resistant for different weather conditions. When there are more layers of tread it is called tread reinforcement ply (13), this is when there are more layers of fabric that strengthen and stabilize the tread area for high speed operation. Futher there are grooves (14) in the tire to lead away the water and provide more grip on the runway.
### Appendix IX  Boeing 737-800 NG tire types

#### Bias tires

<table>
<thead>
<tr>
<th>SIZE</th>
<th>PLY</th>
<th>SPEED RATING</th>
<th>SPEED RATING</th>
<th>TT/TL</th>
<th>PART NUMBER</th>
<th>MANUFACTURER MODEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>24X7.7</td>
<td>16</td>
<td>210 MPH TL</td>
<td>247F63-3 Boeing</td>
<td>B737</td>
<td></td>
<td></td>
</tr>
<tr>
<td>24X7.7</td>
<td>16</td>
<td>210 MPH TL</td>
<td>247F63T2 Boeing</td>
<td>B737</td>
<td></td>
<td></td>
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<tr>
<td>24X7.7</td>
<td>16</td>
<td>225 MPH TL</td>
<td>247F62-1 Boeing</td>
<td>B737</td>
<td></td>
<td></td>
</tr>
<tr>
<td>27X7.75-15</td>
<td>12</td>
<td>225 MPH TL</td>
<td>Boeing</td>
<td>B737</td>
<td></td>
<td></td>
</tr>
<tr>
<td>27X7.75-15</td>
<td>12</td>
<td>225 MPH TL</td>
<td>275K22-1 Boeing</td>
<td>B737</td>
<td></td>
<td></td>
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<tr>
<td>27X7.75-15</td>
<td>12</td>
<td>225 MPH TL</td>
<td>275K22T1 Boeing</td>
<td>B737</td>
<td></td>
<td></td>
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<tr>
<td>40X14</td>
<td>24</td>
<td>225 MPH TL</td>
<td>404F42T2 Boeing</td>
<td>B737</td>
<td></td>
<td></td>
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<tr>
<td>H40X14.5-19</td>
<td>225</td>
<td>MPH TL</td>
<td>419K62T2 Boeing</td>
<td>B737</td>
<td></td>
<td></td>
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<tr>
<td>H40X14.5-19</td>
<td>26</td>
<td>225 MPH TL</td>
<td>419K62T1 Boeing</td>
<td>B737</td>
<td></td>
<td></td>
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<tr>
<td>H40X14.5-19</td>
<td>26</td>
<td>225 MPH TL</td>
<td>419K62T1 Boeing</td>
<td>B737</td>
<td></td>
<td></td>
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<tr>
<td>H40X14.5-19</td>
<td>24</td>
<td>225 MPH TL</td>
<td>419K42T1 Boeing</td>
<td>B737</td>
<td></td>
<td></td>
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<td>H40X14.5-19</td>
<td>24</td>
<td>225 MPH TL</td>
<td>419K42-3 Boeing</td>
<td>B737</td>
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<td>H42X16.0-19</td>
<td>26</td>
<td>225 MPH TL</td>
<td>426K62-2 Boeing</td>
<td>B737</td>
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<tr>
<td>H43.5X16.0-216</td>
<td>26</td>
<td>225 MPH TL</td>
<td>431K62-1 Boeing</td>
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<td>H44.5X16.5-212</td>
<td>225</td>
<td>MPH TL</td>
<td>441K82T1 Boeing</td>
<td>B737</td>
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<td>H44.5X16.5-218</td>
<td>225</td>
<td>MPH</td>
<td>441K82-1 Boeing</td>
<td>B737</td>
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<td>H44.5X16.5-212</td>
<td>225</td>
<td>MPH TL</td>
<td>9856 Boeing</td>
<td>B737</td>
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#### Radial tires

<table>
<thead>
<tr>
<th>SIZE</th>
<th>PLY</th>
<th>SPEED RATING</th>
<th>SPEED RATING</th>
<th>TT/TL</th>
<th>PART NUMBER</th>
<th>MANUFACTURER MODEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>27X7.75R15</td>
<td>12</td>
<td>225 MPH TL</td>
<td>275Q22-1 Boeing</td>
<td>B737</td>
<td></td>
<td></td>
</tr>
<tr>
<td>27X7.75R15</td>
<td>12</td>
<td>235 MPH TL</td>
<td>275Q29-1 Boeing</td>
<td>B737</td>
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</table>
Appendix X  Radial tire

Legend:
1. Wire beads
2. Apex strip
3. Casing plies
4. Ply turn-ups
5. Chippers
6. Bead toe
7. Bead heel
8. Inner liner
9. Buff line cushion
10. Belts plies
11. Tread
12. Tread reinforcing ply
13. Grooves

The wire beads (1) are hoops of high tensile strength steel wire which anchor the casing plies and provide a firm mounting surface on the wheels. On the side of the wire beads are apex strip (2) these layers of rubberized fabric help anchor the bead wires to the casing and improve the durability of the tire. The casing plies (3) are anchored by wrapping them around the wire beads, so they can form the plyturnups (4) which made the tire stronger. To minimize the chafing there are chippers (5). To prevent any nitrogen is leaking the tire need to fit exactly. The bead toe (6) and the bead heel (7) are the inner bead edge and prevent leaking because it fits exactly against the wheel flange. The inside of the tire is also called the innerline (8), this because in tubeless tires the inner layers acts as a built in tube and restrict the nitrogen from diffusing into the casing plies. On top of the tire there are also reinforcements they called buff line cushion (9) and bels plies (10). These reinforcements provide an stabilize area and the tick layer of rubber is of sufficient thickness to allow for the removal of the old tread when the tire is retreaded. Tread (11) is made of rubber and compounded for toughness. This compound is resistance for different weather conditions. When there are more layers of tread it is called tread reinforcement ply (12) this is when there are more layers of fabric that strengthen and stabilize the tread area for high speed operation. Further there are grooves (13) in the tire to lead away the water and have more grip on the runway.
Appendix XI  Landing gear lever assembly

The landing gear control lever assembly is visualized here. The upper image shows the front part of the assembly that is fit in the cockpit. The lower image shows the system assembly.
Appendix XII  Forward control quadrant

The forward control quadrant is shown here. The first image shows the position of the main parts of the LG control system. The second image shows the forward control quadrant assembly.
Appendix XIII  Transfer valve

This image visualizes the landing gear control system with the system components.
Appendix XIV  Down lock mechanism and actuator

The left image shows the left main landing gear. The right image is an enlargement of the down lock mechanism and actuator.
Appendix XV  Main landing gear actuator

The left image shows the left main landing gear when looking a little bit backwards. The image under it shows the main landing gear Actuator and the mechanism where it is fit. The two images on the right show the retraction process of the main landing gear.
Appendix XVI  Main landing gear up lock mechanism

The upper image shows the left main landing gear, where the up lock mechanism is displayed on the right side of the image. The left image under it shows the main landing gear up lock mechanism when it is unlocked. The second image under it shows the up lock mechanism in the locked position with the main landing gear shock strut under it.
The upper image shows a main landing gear extension linkage, which consists of the quadrant and the up lock mechanism. The image under it gives a global view of the positions of the components with two arrows that enlarge the extension linkage and the forward cable quadrant connected to the manual extension handles.
Appendix XVIII  Nose landing gear overview

The nose landing gear of a Boeing 737-800 NG.
Appendix XIX  Nose landing gear lock mechanism

The nose gear lock mechanism of a Boeing 737-800 NG.
Appendix XX  Lever sensors

Sensors
Appendix XXI  Main landing gear sensor
Appendix XXII  Nose landing gear sensors
Appendix XXIII  Hydraulic brake system

Legend:
1. Hydraulic system B
2. Normal brake metering valves
3. Accumulator brake
4. Isolation valve
5. Hydraulic system A
6. Alternate brake selector valve
7. Alternate brake system
8. Alternate brake metering valves

Normal brakes
The hydraulic system B supplies pressure (1). The brakes get metered hydraulic system B pressure from the normal brake metering valves (2). Hydraulic system B pressure also charges the accumulator brake (3) and moves the accumulator isolation valve (4).

Alternate brakes
When the hydraulic system B cannot deliver any pressure the hydraulic system A (5) pressure moves the alternate brake selector valve (6). The alternate brake selector valve sends hydraulic system A pressure to the alternate brake system (7). The brakes then get metered hydraulic system A pressure from the alternate brake metering valves (8). Pressure in the alternate brake system moves the accumulator isolation valve (4).

Accumulator brakes
When hydraulic system A as well B don’t supplies pressure the accumulator pressure moves the accumulator isolation valve (4). The brakes then get brake accumulator pressure from the normal brake metering valves (2).
Appendix XXIV  Checklists

**TAKEOFF CHECKLIST**
- Smoothly increase thrust to 40% N1 let spool up
- Takeoff Thrust FULL or TO/GA
- Brakes RELEASE
- \( V_{1} = 145 \text{ KIAS} \) (decision)
- \( V_{f} = 156 \text{ KIAS} \) (rotate)
- Pitch 10 deg. nose up
- \( V_{2} = 180 \text{ KIAS} \) (safety speed)
- At Positive Climb Rate Touch Brakes
- Landing Gear RETRACT
- At 210 KIAS RETRACT flap up

The checklist of the steps which the pilot needs to take before the aircraft can take off.

**DESCENT CHECKLIST**
- ATIS /Airport Information CHECK
- Altimeter CHECK
- Radios CHECK
- De-ice AS REQUIRED
- Descent Speed to FL240 0.75 mach
to FL180 0.65 mach
- At Transition Altitude (FL180) reset Altimeters to local
to 12,000’ 280 KIAS
Below 10,000’ 250 KIAS
- Fuel Quantities and Balance CHECK
- Flaps /Landing Gear CHECK UP
- Check Weather (ATIS, Flight Service)

The checklist of the steps which the pilot needs to take before the aircraft can decent.

**APPROACH CHECKLIST**
- On Localizer Level flight:
  - Fasten Seat Belts ON
  - No Smoking ON
  - Avionics + Radios SET
  - Speed: Establish 210 KIAS
  - Landing Lights ON
  - Auto Spoilers ARM
  - Autobrake SET
  - Flap Lever Position 5 - 10 deg.
  - Speed: Establish 180 KIAS
  - Flap Lever Position 15 - 20 deg.
  - Speed: Establish 160 KIAS
  - Landing Gear DOWN
  - Set Flap Lever Position 30 deg. or FULL

**Final glide Slope Descent:**
- Speed Establish 145 KIAS
- Elevator Trim AS DESIRED
- Parking Brake VERIFY OFF
- De-ice AS REQUIRED

The checklist of the steps which the pilot needs to take before the aircraft can approach.
LANDING CHECKLIST

Landing Gear
Autopilot
Landing Speed
After Touchdown

Spoilers
Brakes

CHECK DOWN
OFF
140 KIAS
Apply Reverse Thrust
60KIAS: Cancel Reverse Thrust
VERIFY EXTENDED
AS REQUIRED

The checklist of the steps which the pilot needs to take before the aircraft can land.
### Appendix XXV  Limitations

#### OPERATIONAL LIMITATIONS

<table>
<thead>
<tr>
<th>Limitation</th>
<th>Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Operating Altitude (Service Ceiling)</td>
<td>41,000 FT</td>
</tr>
<tr>
<td>Maximum Takeoff Altitude</td>
<td>8,400 FT</td>
</tr>
<tr>
<td>Minimum Altitude for Autopilot use on Takeoff</td>
<td>500 ft AGL</td>
</tr>
<tr>
<td>Maximum Flap Extension Altitude</td>
<td>20,000 FT</td>
</tr>
<tr>
<td>Minimum Speedbrake Deployment Altitude</td>
<td>1000 ft RA</td>
</tr>
<tr>
<td>Final Flap Setting (Procedural)</td>
<td>1000 ft AGL</td>
</tr>
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</table>

#### AMBIENT & ATMOSPHERIC

<table>
<thead>
<tr>
<th>Limitation</th>
<th>Limit</th>
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</thead>
<tbody>
<tr>
<td>Maximum/Minimum Takeoff and Landing Temperature Limits</td>
<td>+54°C/-54°C</td>
</tr>
<tr>
<td>Maximum Fuel Tank Temp</td>
<td>+49°C</td>
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</table>

#### FLIGHT PLANNING & WEIGHT AND BALANCE

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<thead>
<tr>
<th>Limitation</th>
<th>Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operational Envelope</td>
<td>Aircraft must only be operated within the approved weight and balance limits.</td>
</tr>
<tr>
<td>Maximum Distance for Takeoff Alternate</td>
<td>330NM (FM Part 1 Sec 6)</td>
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</tbody>
</table>

#### RUNWAY CONDITIONS

<table>
<thead>
<tr>
<th>Limitation</th>
<th>Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Runway slope</td>
<td>+/- 2%</td>
</tr>
<tr>
<td>Minimum Runway Width</td>
<td>148FT/45 Meters (FM Part 1 Sec 6)</td>
</tr>
<tr>
<td>Takeoff Not Authorized under the following conditions: (FM Part 1 Sec. 8 pg 6)</td>
<td>More than 3 inches of dry snow, More than 1/4 inch of wet snow, More than 1/4 inch of slush or standing water, Chunks of hardened snow or ice</td>
</tr>
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#### WIND LIMITS

<table>
<thead>
<tr>
<th>Limitation</th>
<th>Limit</th>
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</thead>
<tbody>
<tr>
<td>Maximum T/O &amp; Landing Crosswind</td>
<td>36Kts (Demonstrated, Company Policy)</td>
</tr>
<tr>
<td>Maximum T/O &amp; Landing Tailwind</td>
<td>10Kts, Up to 15Kts only if specified by Special Takeoff and Landing Analysis in Performance Manual</td>
</tr>
<tr>
<td>Crosswind Limitations (Landing)</td>
<td>Runway Condition</td>
</tr>
<tr>
<td>- Observe Most Restrictive Limit</td>
<td>Dry</td>
</tr>
<tr>
<td>- Rolling takeoff is strongly advised when crosswind exceeds 20 knots</td>
<td>Fair</td>
</tr>
<tr>
<td>- All winds include gusts</td>
<td>Poor</td>
</tr>
<tr>
<td>- May be further restricted for Restricted Captains (Exemption 5549, FM Part I, Sec. 10)</td>
<td>Visibility</td>
</tr>
<tr>
<td>- For dispatch to an airport, use steady state winds</td>
<td>Instrument Approach</td>
</tr>
<tr>
<td>Runway Width Less than Standard</td>
<td>20Kts (FM Part 1 Sec 6)</td>
</tr>
<tr>
<td>Maximum Tailwind for CAT II and CAT III</td>
<td>10Kts</td>
</tr>
<tr>
<td>Maximum Headwind for CAT II and CAT III</td>
<td>25Kts</td>
</tr>
<tr>
<td>Maximum Wind Gust</td>
<td>50Kts (Except in an emergency)</td>
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#### AIRSPEEDS

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<tr>
<th>Speed</th>
<th>Limit</th>
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</thead>
<tbody>
<tr>
<td>Maximum V Speed (Vmo)</td>
<td>340 knots (observe Vmo pointer and gear/flap placards)</td>
</tr>
<tr>
<td>Maximum Mach Operating Speed (Mmo)</td>
<td>82 Mach</td>
</tr>
<tr>
<td>Turbulent Air Speed</td>
<td>280K/76M</td>
</tr>
<tr>
<td>Maximum Landing Gear Extended</td>
<td>320K/82M</td>
</tr>
<tr>
<td>Maximum Landing Gear Extension</td>
<td>270K/82M</td>
</tr>
<tr>
<td>Maximum Landing Gear Retraction</td>
<td>235K</td>
</tr>
<tr>
<td>Maximum Speed with 1 LED stuck-out</td>
<td>300K/65M (280KIAS in turbulence-QRH, FLT-C)</td>
</tr>
<tr>
<td>Maximum Speed with &gt; 1 LED stuck out.</td>
<td>230K (QRH, FLT-C)</td>
</tr>
<tr>
<td>Maximum Alternate Flap Extension Speed</td>
<td>230K (QRH, FLT-C)</td>
</tr>
<tr>
<td>Elevator Tab Limit Cycle Oscillation (LCO) Speed</td>
<td>270K or less or until the vibration ceases (QRH, FLT-C)</td>
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### ELECTRICAL
**Integrated Drive Generators (IDG)**

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<th>Parameter</th>
<th>Specification</th>
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<tr>
<td>Number</td>
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</tr>
<tr>
<td>Frequency</td>
<td>400 Hz ±10 Hz</td>
</tr>
<tr>
<td>Voltage</td>
<td>115 Volts ±5 Volts</td>
</tr>
<tr>
<td>Rated Output</td>
<td>90 KVA</td>
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<tr>
<td>Normal Battery Voltage</td>
<td>26 Volts ±4 Volts</td>
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</table>

### FLIGHT CONTROLS

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<tr>
<th>Condition</th>
<th>Specification</th>
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<tbody>
<tr>
<td>Holding in Icing Conditions</td>
<td>Prohibited with flaps extended (AFM)</td>
</tr>
<tr>
<td>Minimum Altitude for deployment of Speed brakes</td>
<td>Do not deploy speed brakes in flight at radio altitudes below 1000 FT (AFM)</td>
</tr>
<tr>
<td>Speed Brake extension limit</td>
<td>In flight, do not extend Speed Brake Lever beyond the FLIGHT deck (AFM)</td>
</tr>
<tr>
<td>Maximum flap extension altitude</td>
<td>20,000 feet (AFM)</td>
</tr>
</tbody>
</table>
MISCELLANEOUS LIMITATIONS

AUTOFLIGHT

- Autopilot use after takeoff: Do not engage autopilot below 500 AGL
- Single Channel Operations during approach: Autopilot shall not remain engaged below 50 FT AGL (AFM)
- Aileron Trim: Must not be used with autopilot engaged
- Minimum Altitude during Non-ILS Approaches: Autopilot must not be engaged below 50 FT below the MDA
- Dual Channel Autopilot Approaches: Prohibited

COMMUNICATIONS

- HF Radio Operations: If one HF radio is selected for transmission, deselect the other HF radio on all audio select panels to prevent audio interference.
- HF Radio Power Output: Modulation Technique
  - USB: 400 Watts PEP
  - AM: 125 Watts

FUEL

- Minimum Dispatch Fuel: See FAR 121.639, 121.647 (FM Part 1 Sec 6)
- Reserve Fuel (45 minutes): 4,080 LBS (for manual flight planning purposes)
- Maximum Fuel Capacity: 48,000 LBS – 6,875 Gallons (6.7 lbs/U.S. gallon)
- Tank 1 and 2 Capacity: 8,600 LBS – 1,289 Gallons
- Center Tank Capacity: 23,800 LBS – 4,299 Gallons
- Minimum Fuel for ground operation of Electrical Hydraulic Pumps: 1,675 LBS in related Main tank. (OM II – Hydraulics)
- Ballast Fuel: NOT AUTHORIZED
- Crossfeed Valve: Must be closed for Takeoff & Landing
- Maximum Lateral Moment: Main tanks 1 and 2 must be full if center tank contains more than 1000 LBS
- Maximum Lateral Imbalance:
  - Tank 1 and Tank 2 must be scheduled to ZERO
  - Random fuel imbalance must not exceed 1000 LBS for taxi, takeoff, flight or landing

Center Tank Fuel Pumps (AFM)

- For Ground Ops, Center Tank Fuel Pump Switches must not be ON unless the center tank fuel quantity exceeds 1000 pounds, except when defueling or transferring fuel.
- Center Tank Fuel Pump Switches must be turned OFF when both center tank fuel pump LOW PRESSURE lights illuminate. If a center tank fuel pump LOW PRESSURE Light(s) illuminate during takeoff or climb, the center tank pump(s) may remain on until the climb attitude is reduced and the light(s) extinguish or workload allows for the pumps to be turned OFF.
- Center Tank Fuel Pumps must not be ON unless personnel are available in the flight deck to monitor LOW PRESSURE Lights.

Fuel Specifications (Systems)
- Standard Fuels: Jet A and Jet A-1
- Prohibited Fuels: JP-4 and Jet B

Refueling (Systems)

- (Do not operate HF or WX radar [except in test mode], ground equipment must be positioned under wing-tips, fuel supply unit and aircraft must be properly bonded [ground wires])
  - No.1 and No.2 Main tanks should normally be scheduled equally until full, additional fuel is then loaded into Center Tank.
  - Main tanks must be scheduled full if the Center tank contains more than 1000 pounds. With less than 1000 pounds of center tank fuel, partial main tank fuel may be loaded provided the effects of balance have been considered.
  - Recommended maximum nozzle pressure is 50 psi, this is approximately 300 U.S. gallons per minute.
  - A fueling control panel containing all the controls required for operation of the refueling system is located in the lower leading edge of the right wing.
### MISCELLANEOUS LIMITATIONS

<table>
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<tr>
<th>LANDING GEAR and TIRES</th>
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<tbody>
<tr>
<td><strong>Brakes</strong></td>
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<tr>
<td><strong>Tire Pressure</strong></td>
</tr>
<tr>
<td><strong>Maximum Tire Speed</strong></td>
</tr>
</tbody>
</table>

### OXYGEN

| Minimum Crew Oxygen for Dispatch | 1000 PSI Recommended. See Preflight and MEL 35-2 for pressure/temperature chart. |
| Maximum Preflight Oxygen pressure | 1650 PSI |
| Normal Duration of Passenger Oxygen | 12 mins |

### POWERPLANT

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<th>Powerplant</th>
<th>CFM56-7B26</th>
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</thead>
<tbody>
<tr>
<td>22K, 24K, 26K, 27K Max Power Rating. Produces 26,400 LBS of static thrust at Sea Level (27,000 Lbs Thrust Bump Orange County (SNA) only)</td>
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<tr>
<td>Reverse Thrust</td>
<td>Intentional use of reverse thrust inflight is prohibited</td>
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<tr>
<td>Engine Display Markings</td>
<td>RED: Maximum and Minimum</td>
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<tr>
<td></td>
<td>AMBER: Caution limits</td>
</tr>
<tr>
<td></td>
<td>GREEN: Normal limits</td>
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<tr>
<td>EEC Operations</td>
<td>Both EEC’s must be ON for Takeoff.</td>
</tr>
<tr>
<td></td>
<td>If EECs are in Alternate mode for Takeoff:</td>
</tr>
<tr>
<td></td>
<td>• Both EEC’s must be in Alternate mode</td>
</tr>
<tr>
<td></td>
<td>• 26K (27K Max at KSNA) takeoff thrust must be used</td>
</tr>
<tr>
<td></td>
<td>• Do not use the FMS takeoff N1 or V-Speed values</td>
</tr>
<tr>
<td></td>
<td>• Use of aut throttule for takeoff is prohibited</td>
</tr>
<tr>
<td>Engine Ignition Must Be On</td>
<td>TILT OVER</td>
</tr>
<tr>
<td></td>
<td>Takeoff [CONT or AUTO]</td>
</tr>
<tr>
<td></td>
<td>Icing Conditions (Anti-Ice operations) [CONT or AUTO]</td>
</tr>
<tr>
<td></td>
<td>Landing [CONT or AUTO]</td>
</tr>
<tr>
<td></td>
<td>Turbulence (Maneuvers [FLT])</td>
</tr>
<tr>
<td></td>
<td>Operating in heavy rain [CONT]</td>
</tr>
<tr>
<td></td>
<td>Volcanic Ash [ORH MISC, [FLT]</td>
</tr>
<tr>
<td></td>
<td>Emergency Descents (Maneuvers/ORH 12.1 [CONT])</td>
</tr>
<tr>
<td></td>
<td>Training Test &amp; Thrust Bump Flights</td>
</tr>
</tbody>
</table>

### FLIGHT DECK DOOR and ACCESS SYSTEM

| Reinforced Flight Deck Door and Flight Deck Access System (AFM) | Accomplish Pre-Flight check prior to the first flight of the day |

### WEATHER RADAR

| Weather Radar | Do not operate weather radar during fuelling, near fuel spills, or people |

### WEIGHTS

<table>
<thead>
<tr>
<th>Weights</th>
<th>Pounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Taxi Weight</td>
<td>174,700 lbs</td>
</tr>
<tr>
<td>Maximum Takeoff Weight (TOW)</td>
<td>174,200 lbs</td>
</tr>
<tr>
<td>Maximum Landing Weight</td>
<td>144,000 lbs</td>
</tr>
<tr>
<td>Maximum Zero Fuel Weight (ZFW)</td>
<td>136,000 lbs</td>
</tr>
<tr>
<td>SYSTEM &amp; SEQUENCE NUMBER</td>
<td>ITEM</td>
</tr>
<tr>
<td>--------------------------</td>
<td>------</td>
</tr>
<tr>
<td>32 - LANDING GEAR</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
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<tr>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
</tr>
<tr>
<td>SYSTEM &amp; SEQUENCE NUMBER</td>
<td>ITEM</td>
</tr>
<tr>
<td>--------------------------</td>
<td>------</td>
</tr>
<tr>
<td>32 - LANDING GEAR</td>
<td></td>
</tr>
<tr>
<td>6. Landing Gear Warning and Indicating System (-100/-200/300/-400/-500)</td>
<td>C-2</td>
</tr>
<tr>
<td>1) Secondary Gear Warning System (Penco F/QC and COMBI)</td>
<td>B-1</td>
</tr>
<tr>
<td>7. Automatic Brake System</td>
<td>C-1</td>
</tr>
<tr>
<td>8. Rudder Pedal Nose Wheel Steering System</td>
<td>C-1</td>
</tr>
<tr>
<td>9. Direct Reading Tire Pressure Gauge</td>
<td>D-2</td>
</tr>
<tr>
<td>10. Alternate Antiskid Valves (-300/-400/-500/-600/-700/-800/-900)</td>
<td>C-2</td>
</tr>
<tr>
<td>11. Brake Temperature Monitor System</td>
<td>C-1</td>
</tr>
<tr>
<td>12. Nose Wheel Steering Switch (-300/-400/-500/-600/-700/-800/-900)</td>
<td>C-1</td>
</tr>
<tr>
<td>SYSTEM &amp; SEQUENCE NUMBER</td>
<td>ITEM</td>
</tr>
<tr>
<td>--------------------------</td>
<td>------</td>
</tr>
<tr>
<td>32 - LANDING GEAR</td>
<td></td>
</tr>
<tr>
<td>13. Hydr. Brake Pressure</td>
<td>C</td>
</tr>
<tr>
<td>1) (-100/-200)</td>
<td></td>
</tr>
<tr>
<td>a) Wheel Well Brake</td>
<td>C</td>
</tr>
<tr>
<td>Brake Accumulator</td>
<td></td>
</tr>
<tr>
<td>Gauges</td>
<td></td>
</tr>
<tr>
<td>b) Flight Deck HYD</td>
<td>C</td>
</tr>
<tr>
<td>BRAKE PRESS Indicator</td>
<td></td>
</tr>
<tr>
<td>Systems</td>
<td></td>
</tr>
<tr>
<td>2) (-300/-400/-500/</td>
<td>C</td>
</tr>
<tr>
<td>-600/-700/-800/-900)</td>
<td></td>
</tr>
<tr>
<td>a) Wheel Well Brake</td>
<td>C</td>
</tr>
<tr>
<td>Brake Accumulator</td>
<td></td>
</tr>
<tr>
<td>Gauge</td>
<td></td>
</tr>
<tr>
<td>b) Flight Deck HYD BRAKE</td>
<td>C</td>
</tr>
<tr>
<td>BRAKE PRESS Indicator</td>
<td></td>
</tr>
<tr>
<td>Systems</td>
<td></td>
</tr>
<tr>
<td>14. Gear Retraction</td>
<td>C</td>
</tr>
<tr>
<td>Braking System (-600/-700/</td>
<td></td>
</tr>
<tr>
<td>800/-900)</td>
<td></td>
</tr>
<tr>
<td>15. Landing Gear</td>
<td></td>
</tr>
<tr>
<td>Selector Valve Bypass</td>
<td>C</td>
</tr>
<tr>
<td>Module (-600/-700/-800/</td>
<td></td>
</tr>
<tr>
<td>-900)</td>
<td></td>
</tr>
<tr>
<td>SYSTEM &amp; SEQUENCE NUMBER</td>
<td>ITEM</td>
</tr>
<tr>
<td>--------------------------</td>
<td>------</td>
</tr>
<tr>
<td>32 - LANDING GEAR</td>
<td></td>
</tr>
</tbody>
</table>

13. Hydraulic Brake Pressure Indication System

1) (-100/-200)
   a) Wheel Well Brake Accumulator Gauges C 2 0 May be inoperative provided associated Flight deck brake pressure indicator operates normally.
   b) Flight Deck HYD BRAKE PRESS Indicator Systems C 2 1 (M) One brake indication (A or B) may be inoperative provided associated brake accumulator charge is verified normal once each flight day.

2) (-300/-400/-500/ -600/-700/-800/ -900)
   a) Wheel Well Brake Accumulator Gauge C 1 0 May be inoperative provided Flight deck brake pressure indicator operates normally.
   b) Flight Deck HYD BRAKE PRESS Indicator System C 1 0 (M) May be inoperative provided brake accumulator charge is verified normal once each flight day.

14. Gear Retraction Braking System (-600/-700/-800/ -900)

15. Landing Gear Selector Valve Bypass Module (-600/-700/-800/ -900)

<table>
<thead>
<tr>
<th>NUMBER REQUIRED FOR DISPATCH</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>NUMBER INSTALLED</th>
</tr>
</thead>
</table>

4. REMARKS OR EXCEPTIONS

- (O) May be inoperative provided:
  a) After takeoff, landing gear remains extended for two minutes before retraction, and
  b) Takeoff performance is based on Landing Gear Extended.

- (M)(O) May be inoperative provided it is deactivated in normal position.
<table>
<thead>
<tr>
<th>SYSTEM &amp; SEQUENCE NUMBER</th>
<th>ITEM DESCRIPTION</th>
<th>NUMBER INSTALLED</th>
</tr>
</thead>
<tbody>
<tr>
<td>32 - LANDING GEAR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>22. Two-position Tail Skid (Cont’d)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2) (-900ER)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) Retraction Mechanism</td>
<td>C 1</td>
<td>0 (M) May be inoperative provided:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>a) Tail skid is secured in retracted position, and</td>
</tr>
<tr>
<td></td>
<td></td>
<td>b) Appropriate performance adjustments are applied.</td>
</tr>
<tr>
<td></td>
<td>C 1</td>
<td>0 (M) May be inoperative provided:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>a) Tail skid is secured in extended position, and</td>
</tr>
<tr>
<td></td>
<td></td>
<td>b) Appropriate performance adjustments are applied.</td>
</tr>
<tr>
<td>b) Cartridge Core Assembly</td>
<td>B 1</td>
<td>0 (M) May be inoperative provided:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>a) Detailed AMM inspection reveals no internal and external structural damage,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>b) Tail skid is secured in retracted position, and</td>
</tr>
<tr>
<td></td>
<td></td>
<td>c) Appropriate performance adjustments are applied.</td>
</tr>
</tbody>
</table>

3. NUMBER REQUIRED FOR DISPATCH

4. REMARKS OR EXCEPTIONS
<table>
<thead>
<tr>
<th>SYSTEM &amp; SEQUENCE NUMBER</th>
<th>ITEM</th>
<th>NUMBER INSTALLED</th>
<th>REMARKS OR EXCEPTIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>32 - LANDING GEAR</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20. Landing Gear Frangible Fitting (-600/-700/-800/-900)</td>
<td>C 2</td>
<td>0</td>
<td>(M) May be broken or missing provided fitting is replaced with a hydraulic cap assembly.</td>
</tr>
</tbody>
</table>
| 21. Flap Landing Warning Switch, S138 (-600/-700/-800/-900) | C 1 | 0 | (M) Switch contacts normally in use may be inoperative provided:  
  a) S138 switch is rewired using an alternate set of contacts, and  
  b) PSEU BITE is used to verify normal operation of S138 switch. |
| 22. Two-position Tail Skid |      |                  |                       |
| 1) (-800)                |      |                  |                       |
| a) Retraction Mechanism  | C 1 | 0 | (M)(O) May be inoperative provided:  
  a) Tail skid is secured in retracted position, and  
  b) Appropriate performance adjustments are applied. |
| b) Cartridge Core Assembly | B 1 | 0 | (M)(O) May be inoperative provided:  
  a) Detailed AMM inspection reveals no internal and external structural damage,  
  b) Tail skid is secured in retracted position, and  
  c) Appropriate performance adjustments are applied. |

(Continued)
Appendix XXVII  Free body diagrams

The free body diagram of a static situation, the aircraft does not move so the minimum of forces are applied on the aircraft.

During taxi the aircraft experiences more forces than in its static situation. The aircraft experiences friction.
When the aircraft makes a rejected take of the forces in the nose landing gear (1) will become bigger than the force in the main landing gear (2).

During the landing the aircraft only experiences forces on the main landing gear. The aircraft lands on the main landing gear so this gear experiences the biggest force.
Appendix XXVIII  Four bar linkage configurations

Drag-link
\[ s \neq p + q \]  
(continuous motion)

Crank-rocker
\[ s \neq p + q \]  
(continuous motion)

Double-rocker
\[ s \neq p + q \]  
(no continuous motion)

Parallelogram linkage
\[ s \neq p + q \]  
(continuous motion)
**Appendix XXIX**  
**Main landing gear and nose landing gear four-bar linkage configuration**

**Main landing gear**

![Diagram of main landing gear]

Legend:
1. Fuselage bar

**Nose landing gear**

![Diagram of nose landing gear]

Legend:
1. Fuselage bar
Appendix XXX Calculations on static forces and moments

The static situation is an equilibrium, that means the sum of all forces is zero. The aircraft weight is divided over the nose- and main gear. The nose gear bears 15% and the main gear bears 85% of the weight. Formulas are required to calculate the acting forces on the landing gear.

<table>
<thead>
<tr>
<th>Formula</th>
<th>Calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum takeoff weight (MTOW)</td>
<td>MTOW = 79016 kg</td>
</tr>
<tr>
<td>W = m.g</td>
<td>W = 79016 * 9,81 = 775147 kg</td>
</tr>
<tr>
<td>Normal force NG (Nₐ) = 0,15 * W</td>
<td>Nₐ = 0,15 * 775147 = 116272,05 N</td>
</tr>
<tr>
<td>Normal force MG (Nₐ) = 0,85 * W</td>
<td>Nₐ = 0,85 * 775147 = 658874,95 N</td>
</tr>
<tr>
<td>Normal force on each strut (MG)</td>
<td>Nₐ/2 = 658874,95/2 = 329437,48 N</td>
</tr>
</tbody>
</table>

When filling in the equilibrium equations, the static situation is checked.

**Equilibrium equations**

\[ \sum M_B = 0 \]

\[ \sum F_Y = 0 \]

\[ \sum F_x = 0 \]

**Equilibrium equations**

\[ \sum M_B = (-N_a \times 15,6) + (775147 \times 2,34) = 0 \]

\[ = (-116272,05 \times 15,6) + (775147 \times 2,34) = 0 \]

\[ \sum F_Y = N_a + N_a - 775147 = 0 \]

\[ = 116272,05 + 658874,95 - 775147 = 0 \]

There are no acting forces in x-direction.
Appendix XXXI  Free body diagram taxi and calculations

Legend:
1. Weight
2. Normal force MG
3. Normal force NG
4. Thrust
5. Friction NG
6. Friction MG

Taxiing with a constant velocity means the sum of all forces and moments is zero.

**Equilibrium equations**

\[ \sum M_A = (W \times 13.26) - (N_B \times 15.6) = 0 \]
\[ \sum M_A = (775147 \times 13.26) - (658874.95 \times 15.6) = 0 \]
\[ \sum F_Y = -W + N_A + N_B = 0 \]
\[ \sum F_Y = -775147 + 116272.05 + 658874.95 = 0 \]
\[ \sum F_x = F_{\text{thrust}} - F_{W,B} - F_{W,A} = 0 \]
\[ \sum F_x = 15502.9 - 13177.5 - 2325.4 = 0 \]
**Appendix XXXII  Stress calculations on the main landing gear shock strut**

The following numbers are needed in order to calculate normal stress in the main landing gear shock strut:

- The shock strut has a diameter of 213,4 mm. So the radius is 106,7 mm
- Gravitational constant: $9,81 \, m/s^2$
- MLW of a Boeing 737-800 NG is 65317 kg.

Consequently, it is possible to calculate the normal stress:

1. $F = \frac{mg}{2}$  \quad \Rightarrow \quad $F = \frac{65317 \cdot 9,81}{2} = 320379,9 \, N$

2. $A = \pi \cdot r^2$  \quad \Rightarrow \quad $A = \pi \cdot 106,7^2 = 35766,7 \, mm^2$

3. $\sigma = \frac{N}{A}$  \quad \Rightarrow \quad $\sigma = \frac{320379,9}{35766,7} = 8,96 \, MPa$  \quad Answer

Legend:
1. Diameter shock strut (213,4 mm)
2. Weight force
Appendix XXXIII Stress calculations on the main landing gear side strut

When calculating the stress in the side strut of the main landing gear, it is necessary to determine the force acting in the side strut. It can be seen that the down force component and the side force component are acting in point A (1) (2). The pull force in the side strut can also be seen (3). Because the normal force (4) is acting vertical, the horizontal component of the side strut will be 0:

\[ +\delta \Sigma M_A = 0 \Rightarrow (F_{B_X} \cdot \sin \theta \cdot x'') = 0 \]
\[ F_{B_X} = 0 \]

Answer

The vertical side strut pull force component is also 0, because the down force component and the normal force absorb the aircraft’s weight force:

\[ +\Sigma F_Y = 0 \Rightarrow 65317 - 65317 + F_{B_Y} \cdot \cos \theta = 0 \]
\[ F_{B_Y} \cdot \cos \theta = 0 \]
\[ F_{B_Y} = 0 \]

Answer

![Diagram of landing gear with labels]

Legend:
1. Down force component
2. Side force component
3. Pull force side strut
4. Normal force

Concluding, the side strut will not absorb any force during a perfect landing. However, if the aircraft lands with a cross wind component or turns during a taxi turn, then there are forces acting on the landing gear’s side strut.
Appendix XXXIV  Stress calculations on the main landing gear wheel axes

When calculating the stress in one wheel axis, it is necessary to know the diameter of this wheel axis (figure x). The diameter of the tire is 0,5 m (2). If the wheel axis is five times smaller in diameter than the tire, the diameter of the wheel axis is 0,1 m, or 100 mm. So the radius is 50 mm. Again, the maximum landing weight of the aircraft is 65317 kg and the gravitational constant is 9,81 m/s². The normal force (same as the weight force) is acting on the tire (1).

The wheel axis is subjected to only the V-force. There is no moment and no N-force. Therefore, the stress must not be calculated as normal stress, but as shear stress (formula 7).

Now all numbers are determined, the shear stress can be calculated:

1. \( F = \frac{mg}{2} \) \( \rightarrow \) \( F = \frac{65317 \cdot 9.81}{4} = 160189.95 \text{ N} \)

2. \( A = \pi \cdot r^2 \) \( \rightarrow \) \( A = \pi \cdot 50^2 = 7853.98 \text{ mm}^2 \)

3. \( \tau = \frac{V}{A} \) \( \rightarrow \) \( \sigma = \frac{160189.95}{7853.98} = 20.4 \text{ MPa} \)  

Concluding, the shear stress in one wheel axis is 20.4 MPa.
Appendix XXXV  Maintenance costs

Note: the possible costs for 12000 landings is not always the same. It depends on which maintenance check is performed.

<table>
<thead>
<tr>
<th>Tires</th>
<th>Costs ($)</th>
<th>Number of tires</th>
<th>After 300 landings tires must be replaced (x4)</th>
<th>Total</th>
<th>Extra costs malfunction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nose wheel</td>
<td>2100</td>
<td>2</td>
<td>4200</td>
<td>16800</td>
<td></td>
</tr>
<tr>
<td>Main landing gear wheel</td>
<td>2900</td>
<td>4</td>
<td>11600</td>
<td>46400</td>
<td>300000</td>
</tr>
<tr>
<td>Carbon heat sink</td>
<td>10 (landing)</td>
<td></td>
<td></td>
<td>120000</td>
<td>400000</td>
</tr>
<tr>
<td>Personal</td>
<td>30(hour)</td>
<td>35</td>
<td>1500</td>
<td>1050000</td>
<td>7200</td>
</tr>
<tr>
<td>Total costs</td>
<td></td>
<td></td>
<td></td>
<td>1233200</td>
<td>707200</td>
</tr>
</tbody>
</table>