

(simplified) Fuselage design

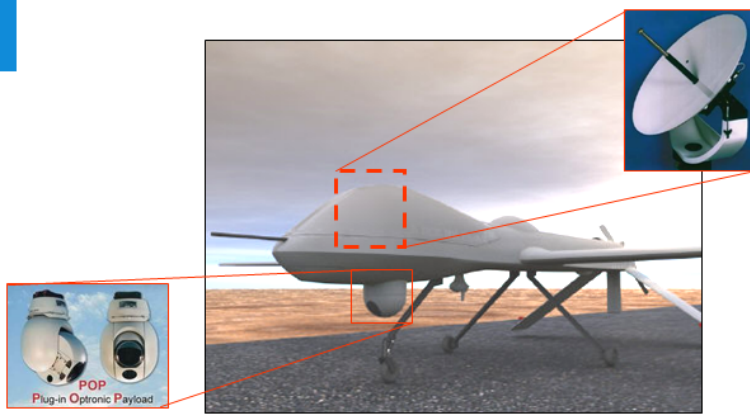
Okay, right, we want to build an airplane, we need to design a fuselage. The following text is a short tutorial that will take you all along on what needs to be considered when designing such structure.

1

It is highly important to know all requirements the airplane will need to be fulfilled. You must know what you are building your airplane for. You MUST. Once you have done that, and already did the first important calculations, you can start designing the fuselage.

In subsonic airplanes, it's usually the payload that drives the design. Another rule of thumb is that the design is built from the inside out (see picture below as example):

Clear example of the inside-out design approach in the General Atomics Predator UAV



2

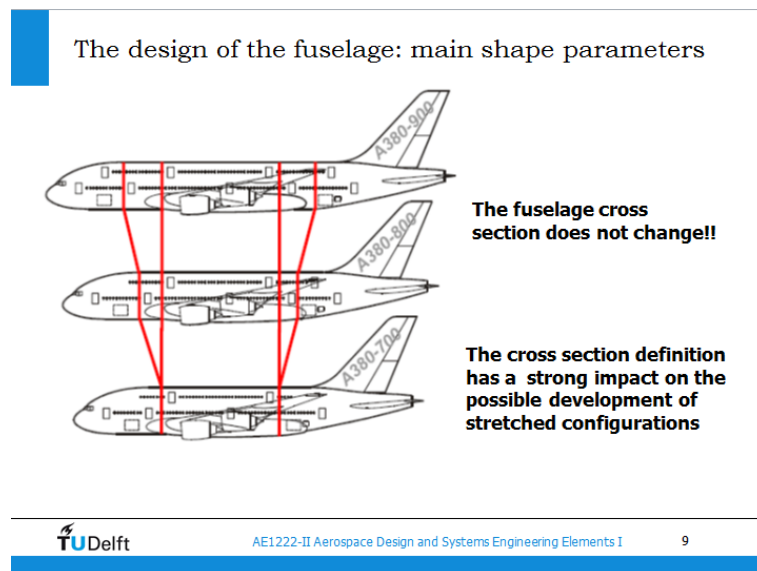
Of course, the larger the fuselage, the more payload you can take, and this at a higher comfort. However, a smaller fuselage will also mean less drag. Remember! Even though payload is the driving factor, you are still interested in other requirements such as range.

The exact diameter and length of the fuselage will be our first dilemma, since it causes 20 - 40% of the total zero drag coefficient.

An increase of 10% in the diameter yields a 2% in drag increase.

Nevertheless, many aircraft companies focus on building a fuselage, whose design allows flexibility. What do I mean with it? Well, it includes various types of flexibilities:

- Usually the cross section in an aircraft, once set, remains fixed. However the length remains as a changing variable, which results in a higher number of aircrafts just like shown below with the A380.



- Then again, you might want to consider different shapes for the cross section. Pressurized aircrafts always tend to have the circular cross section, simply because its the most effective shape that can hold pressures. But then again, not all airplanes are pressurized, and other requirements might be leading, such as comfort of passenger..

Here two examples of airplanes from the slides that do not have circular cross sections:

Examples of non circular fuselage cross sections

The Shorts 360
(Non pressurised cabin)

Source www.aerocondor.fr

Examples of non circular fuselage cross sections

An aircraft or a boat? ...a flyingboat!

Canadair 415

Spray rails

V-shaped hull for water loads resistance

Keel for loads handling and directional stability during water operations

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Still, most passenger airplanes tend to have pressurized fuselages, reason of why there is so much research going on in creating a fuselage that is bigger, better, faster.. One idea is to have both fuselage and wing as one structure, but when one observes the different designs, its obvious that the cylindrical elements are always basic (see picture below)

Examples of non circular fuselage cross sections

Fuselage design studies for a *C-wing* and a *Blended Wing Body* aircraft

32 Floor 127 Business 441 Tourist

	Class	Cabin Ratio (%)	Cabin Ratio (sqm)	Luggage Ratio (%)	Luggage Ratio (sqm)
First	2.3	10.3	24	1.1	
Business	12.2	5.7	14	1.8	
Tourist	85.5	8.3	20	8.0	

(Approximately 700 passengers in an A320 Tourist configuration)

The struggle to fit cylindrical elements in a not cylindrical body

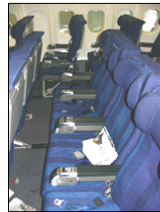
z-position [m]

y-position [m]

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- Lastly, companies tend to build their aircraft in such a way, that their insides are always a choice to the customer. This again shows how crucial it is to have a list of all requirements. See below a few examples that were presented in the lectures:

The design of the fuselage: cabin arrangement



**How flexible
is your
design?**



The design of the fuselage: cabin arrangement

The layout flexibility is an important requirement, both for passengers transport aircraft...



300 seats in three-class arrangement (three class at 60-38-32 pitch)



400 seats in two-class arrangement (two class at 38-32 pitch)



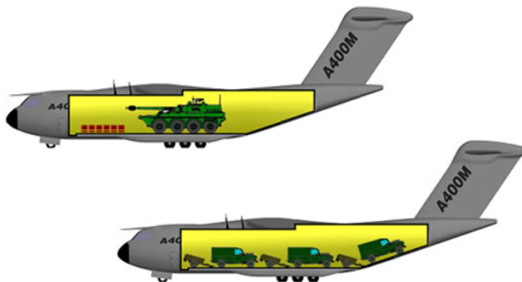
440 seats in a single class (single class at 32 pitch)

**1 aircraft,
3 different
arrangements**

Source: Jenkinson

The design of the fuselage: cabin arrangement

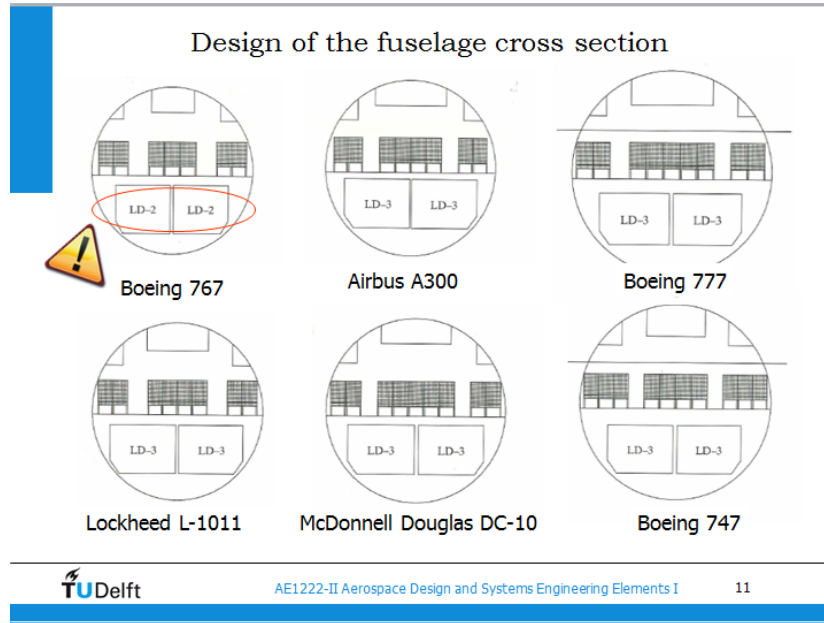
...freighters and military aircraft (both combat and transporters).



Source: www.airbusmilitary.com

3

Once we have a rough idea of what we want from our fuselage, its time to start designing. As said before, one starts the design from the inside out. Lets take a look at a few cross sections:



One notices that the design will need to focus on the seat arrangements, but also on the storage space below the passengers. That space will constrain the shape of the containers.

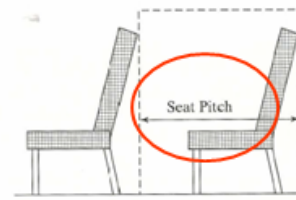
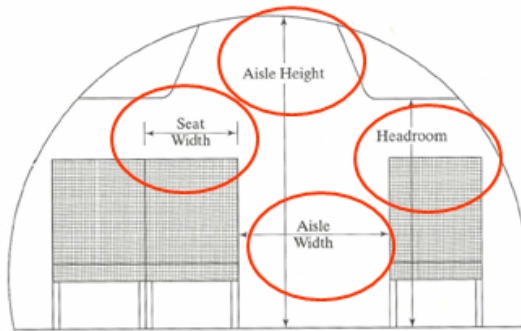
When designing the cargo deck of the fuselage, designers often use the standard container sizes that are widely used by airports all over the world. They are called LD's (load devices). These containers are standardized because it is convenient with respect to the airport luggage transport and management.

Let's focus first of all on the seats and their spacings. These are indicated by parameters according to the aircraft's range: For longer range, the aircraft must guarantee higher level of comfort as well as more baggage. See below the different dimensions and a list of the parameters:

Design of the fuselage cross section

How many aisles? How many decks?

	Long range	Short range
Seat width (in)	17 - 28	16 - 18
Seat pitch (in)	34 - 40	30 - 32
Headroom (in)	> 65	-
Aisle Width (in)	20 - 28	> 15
Aisle Height (in)	> 76	> 60
Lavatories/passengers	1/ (10-20)	1/ (40 -50)
Galley volume/passengers (ft ³)	1- 8	0 - 1
Baggage/passengers (lbs)	40 - 60	40



As a rule of thumb it is said that:

If the nr. of passengers > 150, then install 2 aisles

If the nr. of passengers > 500, then consider 2 decks

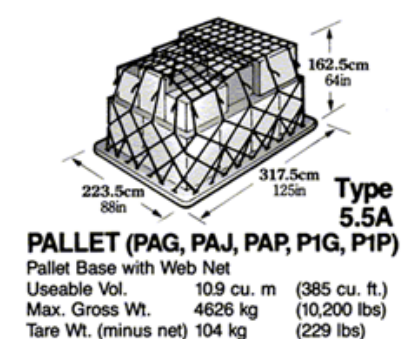
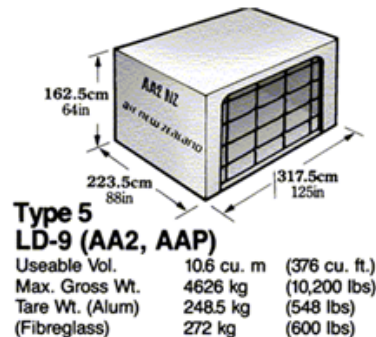
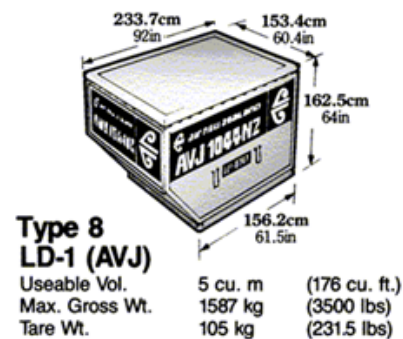
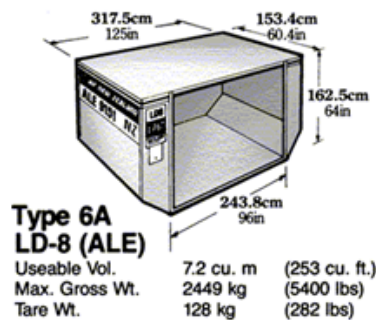
Now to the containers:

As you could see before, the type of container depends a lot on how much space you actually have. It is obvious that the nr. of passengers is proportional to the quantity of luggage your airplane needs to take, which already can give you an idea of the size of your plane.

Also, some cargo will require the need of refrigerator units or similar, for which you will need special containers.

Once done that, you have a whole list of different containers you can choose from. Here the most important ones:

Standard cargo container and pallet

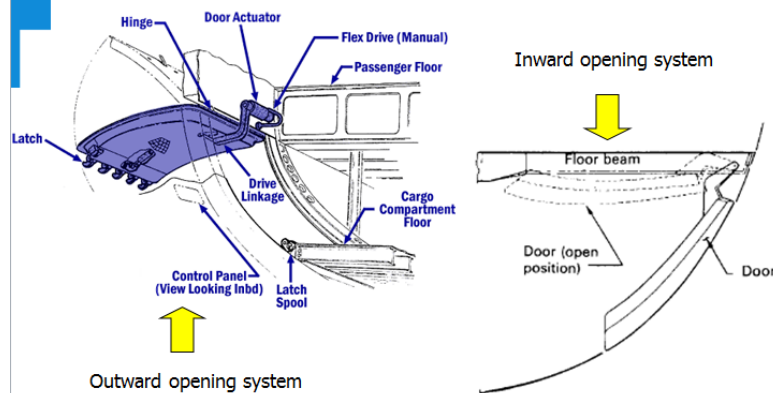


<http://www.airnz.co.nz>

Highly important are also the doors you install on the fuselage.

First of all they are required for ground operations, and usually, you want them to operate your airplane as fast and smooth as possible. There are several types of doors that may be considered, which are installed at the main body, the nose, or the tail of the airplane, which again depend on the requirements. See below a few examples:

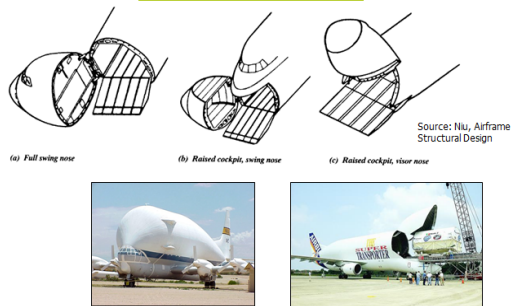
Cargo doors: different side opening systems



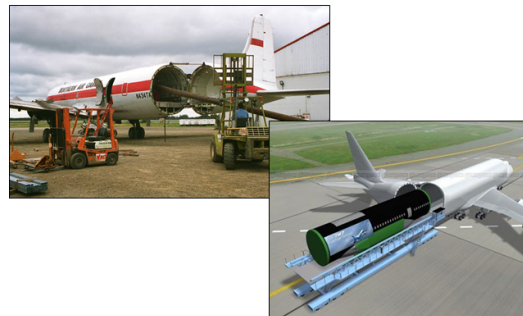
Source: <http://lessons.air.mmac.faa.gov> and Niu

Special fuselage design arrangement for large payload loading

Examples of nose loading design

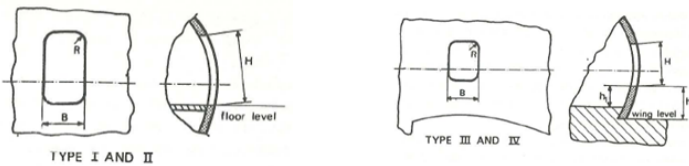


Special fuselage design arrangement for large payload loading



Of course, the doors are not only there for accessibility reasons, but also for emergency purposes. In case there is an evacuation, your aircraft must have enough doors for the passengers to let out in very little time (around 90 secs).

Dimensions of emergency exit



Type	Location	Min. Dimensions Width × Height (in.)	Min. Step Height Inside:Outside (in.)
Type I	Floor Level	24 × 48	—
Type II	Floor Level	20 × 44	—
	Overwing	20 × 44	10:17
Type III	Overwing	20 × 36	24:27
Type IV	Overwing	19 × 26	27:36
Tailcone	Aft of Pressure Hull	20 × 60	24:27
Ventral	Bottom of Fuselage	Equiv. Type I	—
Type A	Floor Level	42 × 72	—

According to CS 25.807

Toorenbeek and Corke

No. Pass.	Type I	Type II	Type III	Type IV
1-9				1
10-19			1	
20-39		1	1	
40-79	1		1	
80-109	1		2	
110-139	2		1	
140-179	2		2	
180-299	Add exits so that 179 plus "seat credits" \geq passenger number.			
	Seat Credit		Exit Type	
	12		Single Ventral	
	15		Single Tailcone	
	35		Pair Type III	
	40		Pair Type II	
	45		Pair Type I	
	110		Pair Type A	
≥ 300	Use pairs of Type A or Type I with the sum of "seat credits" \geq passenger number.			

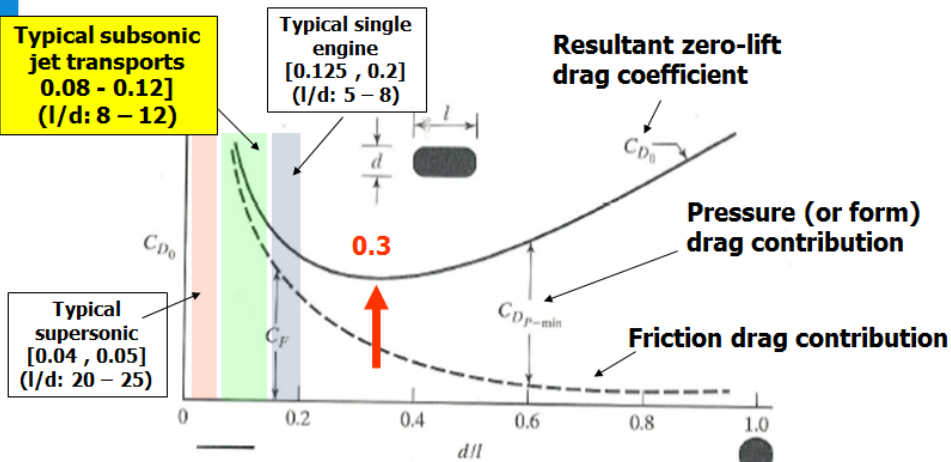
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Now let's take a look at the outer fuselage again.

Again, the fuselage is constrained by both diameter and length. We use the slenderness ratio (l/d) to reduce it all to one constraint. As we had discussed previously, a larger diameter will increase the drag of the aircraft. Still, one can compute the drag vs. the slenderness ratio and see what would be the most appropriate ratio. This one lies around 0.3.

Nevertheless, most aircraft have a slenderness ratio of only 0.1, mostly due to structural reasons or the constraint of other requirements. See below a representation:

The design of the fuselage: aerodynamic considerations

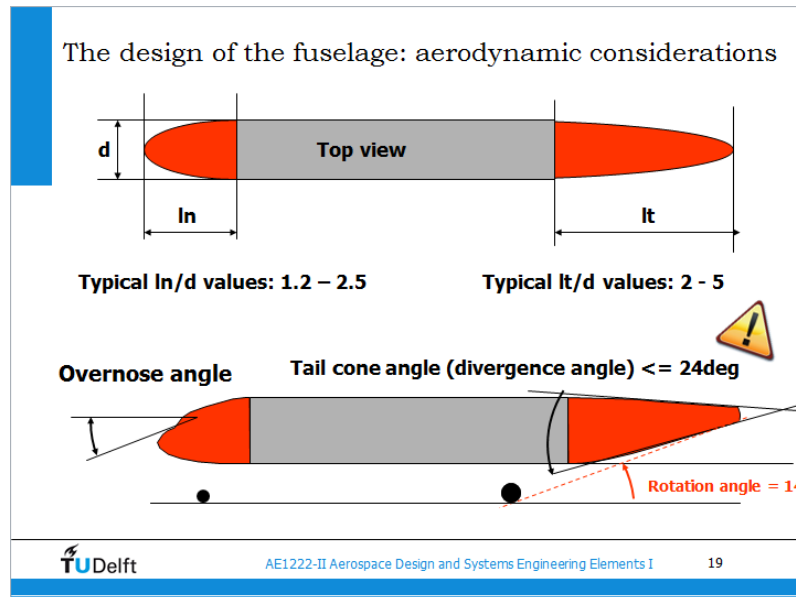


Effect of fineness ratio on the contributions of viscous and pressure drag on the overall drag of a SUBSONIC body

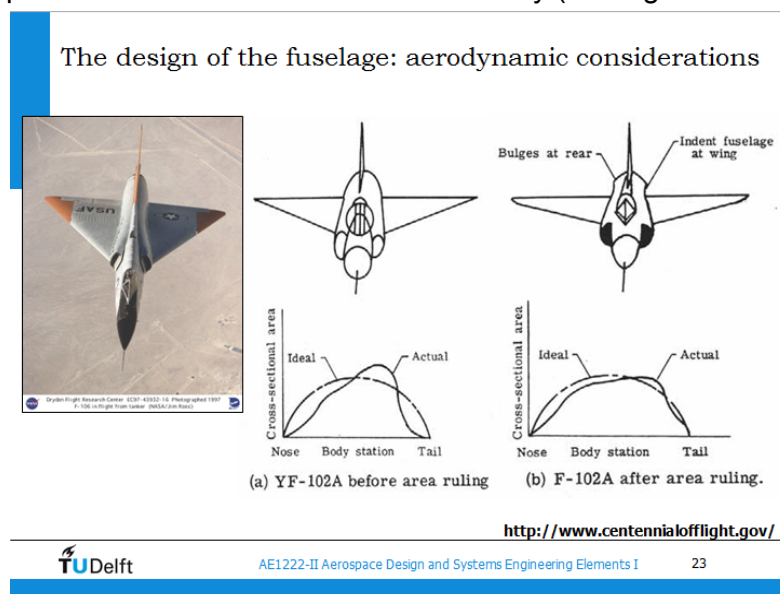
Source Corke

Once we have the slenderness ratio done, we can finally start focusing on the nose and tail of the fuselage. Their design is mainly driven by aerodynamic requirements, which is why the divergence angle the tail can close cannot be larger than 24 degrees. Additionally, the length of the tail is constrained by the rotation angle, which follows from the aircraft rotation when taking off. Again we make use of another two ratios, the (l_n/d) and (l_t/d) , which both tend to be best at values of about 2.

See below a representation of those constraints:

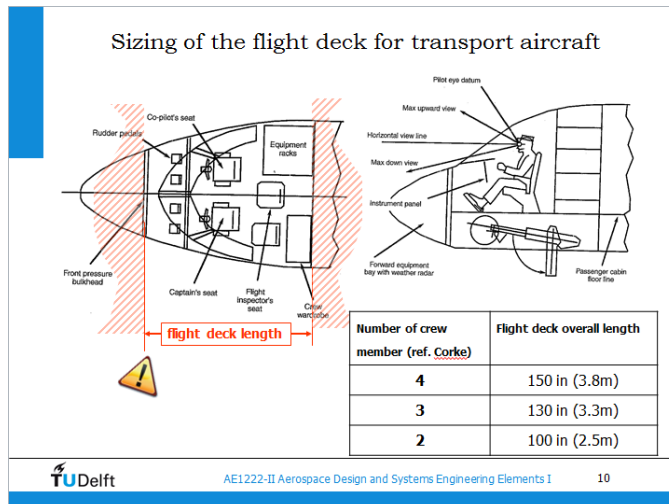


In case of military aircrafts, one might not consider the payload as the driving requirement, but rather the aerodynamic ones. For example, if a supersonic aircraft has to be designed, the shape of the aircraft, which is build around the engines, should approximate as much as possible the so called Sears-Haack body (See figure below)



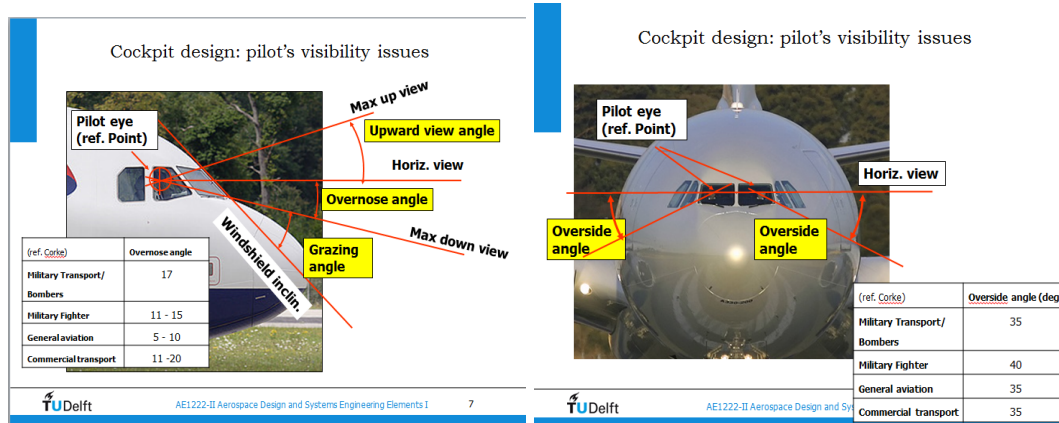
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Lets focus now a bit more on the cockpit. Here, you start designing from the pilots eye. First of all we must know how many crew members there are supposed to be in the cockpit, since parameters will again determine the length of our cockpit (which is measured from pressure bulkhead to rear door):



Once done that, we must assure that the viewing angles of the pilot is large enough to allow proper visibility. It is somewhat obvious that the angles, especially the overnose angle, is dependent on the approaching speed of an aircraft. (Overnose_angle = approach_angle + 0.04 V_approach (V in Km/hr))

See below the list of angles that are important to be considered:



6

Finally, you can complete your first rough fuselage design with the following rules:

- The inner diameter is 4% smaller than the outer diameter of the fuselage.
- The frames pitch of an aircraft's fuselage is about 50 cm.
- The thickness of the floor can be initially estimated 5% of the cross section diameter.