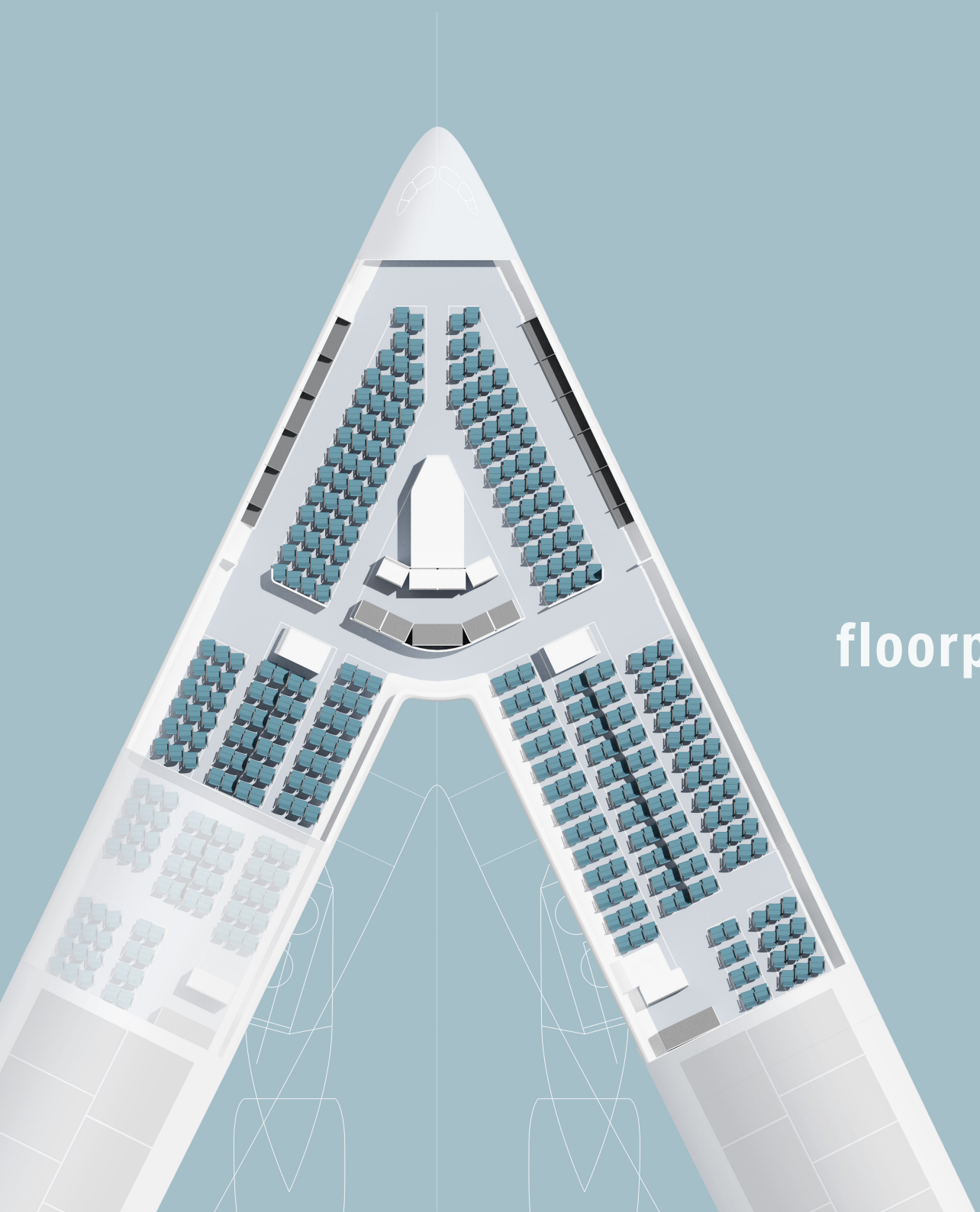

flying-v interior

floorplan design for improved passenger comfort

Lisa Wamelink

Master Thesis

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Faculty of Industrial Design Engineering

TU Delft

Master Thesis
Delft, June 2021

Lisa Wamelink
MSc. Integrated Product Design
Faculty of Industrial Design Engineering
Delft University of Technology

Supervisory Team
Prof. Dr. Peter Vink (Chair)
Ir. Wouter Kets (Mentor)

EX 00

abstract
execute summary

This graduation project investigates the opportunities for the design of a new floorplan concept for the Flying-V aircraft. The aircraft's unique V-shaped layout brings about limitations for how seating and other interior elements such as lavatories and galleys can be placed in the floorplan. Meaning that a different approach needs to be taken regarding the placement of these elements. Regulations for example dictate that aircraft seating cannot be placed at an angle greater than 18° from the direction of flight (DOF), without the need for additional safety precautions such as airbags. Because the passenger cabin of the aircraft is angled at approximately 26°, seats cannot be placed in rows perpendicular to the cabin wall such as in conventional aircrafts.

Additionally, with the design of a new floorplan, opportunities arise for the design of a differentiating passenger experience through improvements in passenger comfort. As described in this report, literature research and an online questionnaire resulted in the definition of five main passenger comfort aspects that are of interest to tackle with the design of a new floorplan: legroom, personal space, boredom, sleeping, and walking or being physically active. Research has shown that these five aspects are considered highly important for passenger comfort, but that they score low with regard to this. Indicating that, if these aspects are improved, overall passenger experience can be improved as well.

Using these outcomes, along with research into the Flying-V's cabin design and geometry, aircraft interior trends and developments, and approaches to aircraft floorplan design, four different design directions were developed. The floorplan concept that is further elaborated on in this report focusses on three of these passenger discomforts: legroom, personal space and the possibility for passengers to walk around the aircraft. Further development of this floorplan aimed to find an appropriate balance between improvements in these aspects and required passenger capacity.

The resulting floorplan proposal contains three different seating configurations, with each seating section dedicated to different types of travel groups: individual travellers, couple travellers, and group travellers.

Firstly, staggered seats facing the DOF are placed at the front of the aircraft and along the outer cabin wall. These seats are dedicated to individual travellers, as they have proven to increase a passengers' sense of individual personal space and legroom.

Secondly, seats dedicated to couple and group travellers are minimally staggered (similar to conventional seating), as this still allows the passenger to easily communicate with their travel partners, one of the drawbacks of seats that are staggered at larger distances. Keeping passenger capacity in mind, the extent to which seats are staggered affects the width of a seating row. So by using a combination of differently staggered seating configurations the width of the aircraft's cabin can be used most optimally. In this floorplan, making the difference between a 9 or 10-abreast configuration.

Additionally, a walking route around the front of the aircraft is created, allowing passengers to be more physically active on long-haul flights, while highlighting of one of the aircrafts unique design features.

CO
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IN 00

introduction
project

With the increasing concerns about the environmental impact of commercial flight, more support is created for the development of aircrafts and propulsion technologies that decrease this impact (International Airport Review, 2019). The new Flying-V aircraft aims to be part of the solution. Its design integrates the passenger cabin, cargo hold and fuel tanks in the wings. The resulting V-shaped design, along with its reduces weight, makes the aircraft 20% more fuel efficient than the Airbus A350, today's most advanced aircraft (TU Delft, n.d.)

Alongside reducing environmental impact, the aircraft unique design brings opportunities for the development of new concepts that improve and/or re-envision passenger experience. Concepts that improve seating, galley design or lavatory design for example are already being developed. (Vink (2020), Lam (2020) and Xao(2019)) Additionally, the aircrafts unique shape requires a different approach to the design if its floorplan. This especially relates to the configuration of seats, since, due to regulations, passengers cannot be seated in the same direction as the aircraft's cabin (approximately 26° from the direction of flight). The design of such a floorplan was the aim of the project described in this report.

This projects design goal and further refinement of the project's scope will be elaborated on in *chapter 1: project design brief*.

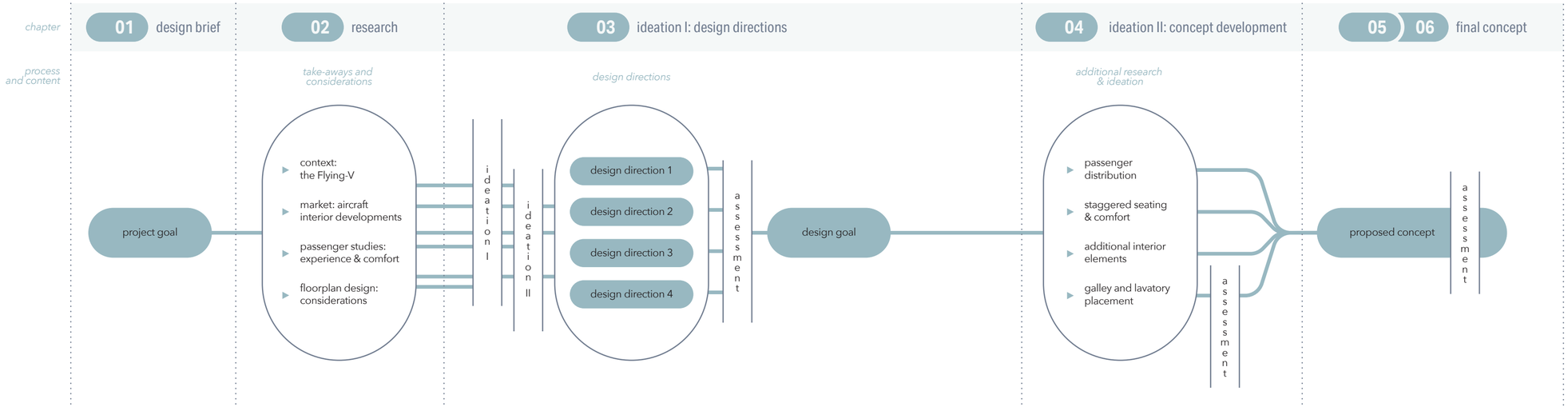
Chapter 2: research: setting the scene describes the initial research done for this project. This chapter is divided into four sections, each describing a different aspect of the project's research. The first section, 'context: flying-v', explores which aspects of the flying-v's design and which existing seating and floorplan concepts need to be taken into consideration when designing a new floorplan. Its second section, 'market studies: trends and developments', explains current themes relating to cabin interiors, which were established by looking at concepts recently introduced on the market. The third section: 'passenger studies', describes several conclusions from literature research and an online survey, which resulted in the formulation of aspects relating to passenger experience and comfort that are of interest to tackle with the design of a new floorplan. Lastly, its third section: 'floorplan design', establishes several aspects that should be taken into account with regards to floorplan design in general and how this could differ from the flying-v's floorplan.

Chapter 3: from design directions to design goal, describes how, through ideation and the development of four different design directions and assessment thereof, a design goal and list of requirements and wishes was created for further development of the floorplan proposal.

Chapter 4: concept development: defining the floorplan, describes the development of this floorplan concept, and delves deeper into how passenger comfort can be increased using the flying-v's floorplan design and seating configurations. Here, different concepts that improve ▸

passenger discomforts are detailed and it's explored how these can be applied to different travel group sizes. The proceeding *chapter 5: proposed concept: interior impressions*, defines the final floorplan proposal and illustrates what it could look like in three-dimensional space.

Lastly, *chapter 6: evaluation and recommendations*, evaluates the concept using the list of requirements defined in chapter 3, and proposes several ways the concept can be improved. Additionally, suggestions are given for further research relating to the proposed concept.



01
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design brief
initial goals

/ 01 project goal

/ 02 stakeholders

/ 03 opportunities and limitations

This thesis project concerns the design of the floorplan and interior of the Flying-V. Different parts of the interior have already been designed to a certain extend. Yet, only limited research and ideation has been done into the floor plan and design features of the interior, and the opportunities the aircraft's unconventional shape brings in relation to the layout and its passenger experience.

01 / project goal

One of the main contributing factors to the need for a new floor plan is the aircrafts shape. The orientation of the passenger cabin is not parallel to the aircraft's direction of flight, it is angled at 26°. According to Federal Aviation Administration (FAA) guidelines, a maximum of 18° variation form the DOF is allowed. In order for the seats to face the DOF, the flying-Vs layout requires passenger seats to be placed at an angle to the wall of the cabin. This brings opportunities for a new unconventional design of the aircrafts floor plan.

This new layout also offers the opportunity to envision and create a passenger experience that is different from current airplanes. Passenger experience is affected by different aspects such as posture, people's movement between areas and choices passengers have in this. As well as other factors influencing comfort and perceived experience, such as: space, light, colour, material, and sound.

Researching the influence of these aspects on current passenger experience gives an idea of how people behave & feel prior to, during, and after the flight. Using these insights, along with opportunities the new layout brings, a vision can be created of what can and should to be changed in the interior design of the flying V.

Project goal: By researching passenger experience on

> *"By researching passenger experience on current airplanes and future airplanes that are being developed, alongside opportunities for a new layout that the shape of the Flying-V offers, I intend to create a vision of what can and needs to change in order to create an appropriate and differentiating passenger experience for the flying-V. This vision can then be used to design a floorplan and (part of) the interior of the cabin that illustrates this new passenger experience."*

02 / stakeholders

Several stakeholders need to be kept in mind when designing the interior of an aircraft. The flying-V is designed by the TU Delft, in collaboration with Airbus and KLM. This manufacturer and airline are mainly concerned with sustainability and profitability of the aircraft, where passenger capacity is one of the main requirements to keep in mind, as well as brand image. Furthermore, when designing the interior of an aircraft, other stakeholders need to be addressed as well, such as manufacturers of interior elements; like aircraft seat manufacturers, and galley manufacturers. The production of these elements need to be feasible, profitable and ideally be applicable to different aircrafts.

03 / opportunities & limitations

The project brings about several opportunities as well as limitations. The main opportunity being the unconventionality of the aircraft, allowing for a completely new look at and design of the floor plan and interior. Additionally, the aircraft's low-impact image, could for example be expressed in the interior as well, by using more sustainable materials or production methods.

Furthermore, several limitations need to be kept in mind as well. One of the main concerns being the passenger capacity of the aircraft, as this will greatly affect profitability. However, maximizing capacity decreases passenger comfort, so a balance between these aspects needs to be found. Additionally, aspects such as safety regulations will impact possibilities within the design.

02
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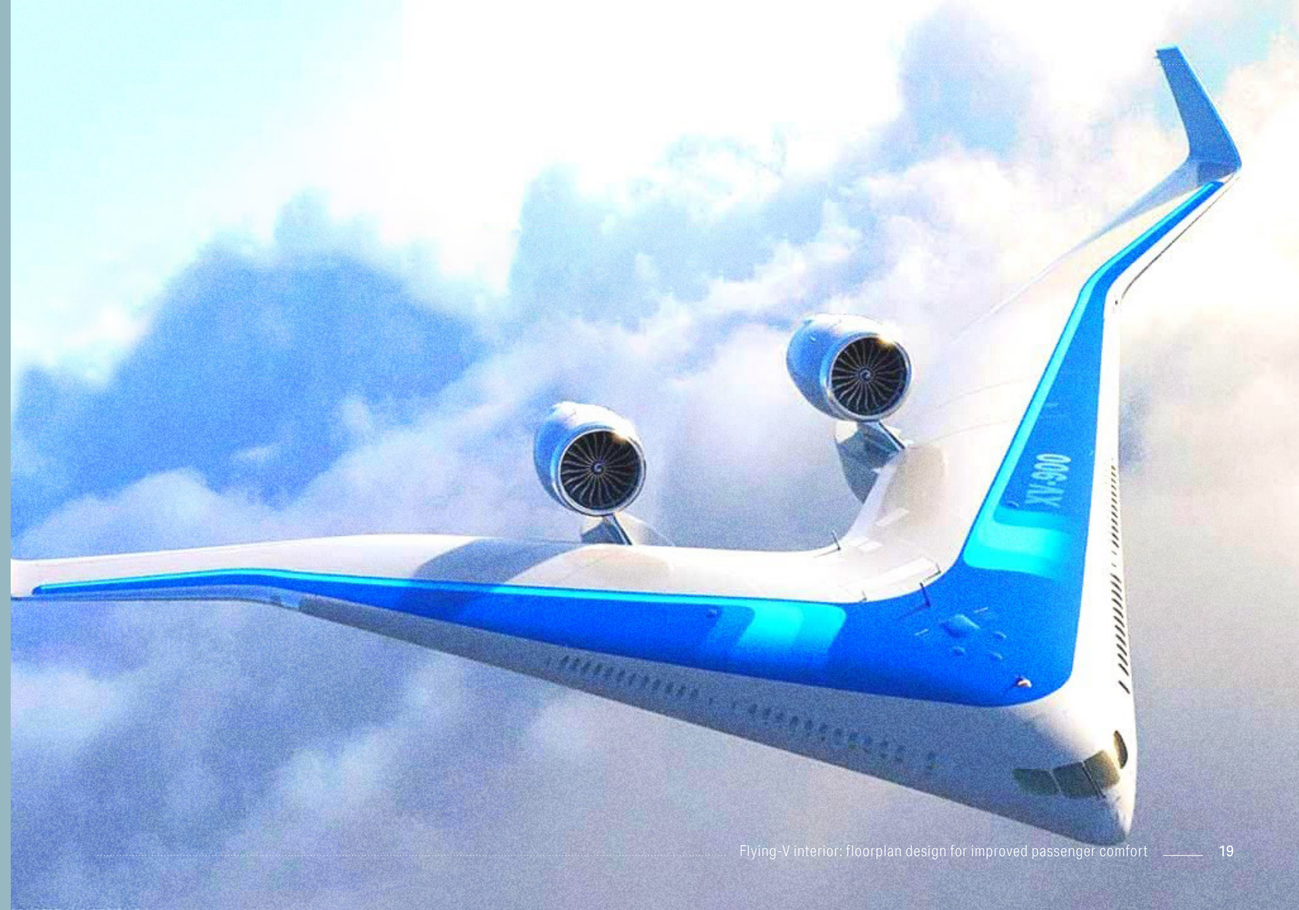
research
setting the scene

/ 01 context: the flying-v

/ 02 market studies: trends and developments

/ 03 passenger studies

/ 04 floorplan design



Flying-V interior: floorplan design for improved passenger comfort

02
01

context: flying-v

01 / concept behind the flying-v

The Flying-V originated as an idea by Justus Benard during his graduation project at Airbus Hamburg. The aircraft is described as: “a long-haul aircraft where the passenger cabin, the cargo hold and the fuel are all located in the wing.” This results in the aircraft having significantly less drag and structural weight than modern widebody aircrafts such as the Airbus 350 or Boeing 787. It is estimated that the aircraft consumes 20% less fuel than a comparable Airbus A350 due to its integrated design. (TU Delft, n.d.) [1]

> *The Flying-V is a long-haul aircraft where the passenger cabin, the cargo hold and the fuel are all located in the wing. We’ve designed an oval pressurized cabin that allows for an efficient structural design, with sufficient design freedom to allow for proper aerodynamic shaping. Our preliminary calculations have shown that the aircraft has significantly less drag than a modern widebody aircraft, such as the Airbus A350 or the Boeing 787. Structural calculations have shown that also the structural weight is significantly lower. Based on those studies we’ve estimated that the Flying-V consumes 20% less fuel than an Airbus A350 for the same flight.*
> *– Roelof Vos (TU Delft, n.d.) [1]*

In addition to consuming 20% less fuel, targets are also to create a CO2-neutral aircraft. TU Delft is researching how such goals can be achieved by for example flying on synthetic kerosine produced by the same amount of CO2 that is emitted during flight, or using other forms of propulsion such as electric and hybrid.

> *Ultimately, we have to fly entirely on sustainable energy. CO2-neutral. If CO2 is still released during the flight, for example because we then fly on synthetic kerosene, the same amount of CO2 will be used to produce those fuels. At Delft University of Technology, we are investigating how we are going to achieve this. For example, we are investigating new forms of propulsion, such as electric and electric hybrid, the climate impact of aviation and air traffic operations, such as airports. – Henri Werij (TU Delft, n.d.) [1]*

02 / previous floorplan designs

Passengers in the Flying-V are located in the two wings, as well as the space at the front of the aircraft connecting the two. The initial floorplan design of the flying-V contains a 10 seats abreast configuration, with seats positioned in the cabin direction. The layout closely resembles contemporary passenger airplanes *(Figure 02-01)*. This initial design partitioned the cabin into three areas: business class, economy class, and a cargo area. This design housed 48 business seats, and 266 economy seats, creating a total of 314 passenger seats, which is similar to an Airbus A350.

However, further research showed that this layout is not possible due to safety restrictions. Federal Aviation Administration (FAA) guidelines dictate that a maximum deviation of 18° from the direction of flight (DOF) is allowed without the need for additional safety precautions. (FAA 2006; USCFR-1988.) Thus, because the passenger cabin of the flying-V is angled 26° from the DOF *(figure 02-02)*, seats cannot be placed parallel to the cabin wall without adding extra safety measures such as airbags. ▸

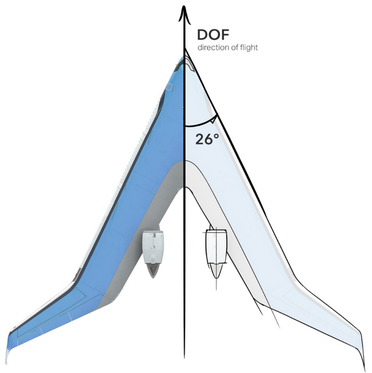


Figure 02-02: Flying-V cabin angle

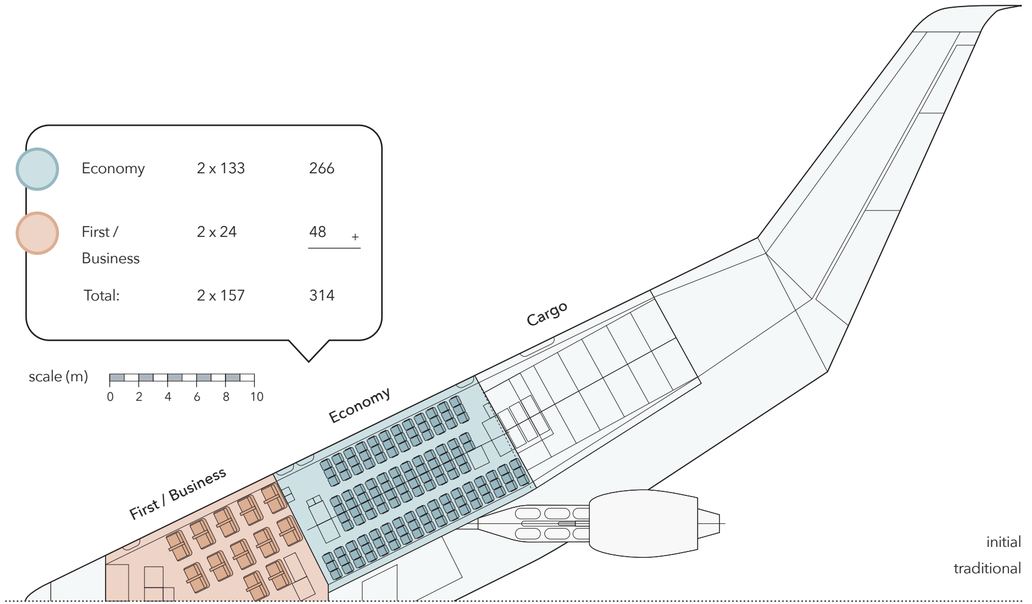


Figure 02-01: Initial Floorplan (TU Delft, n.d.)

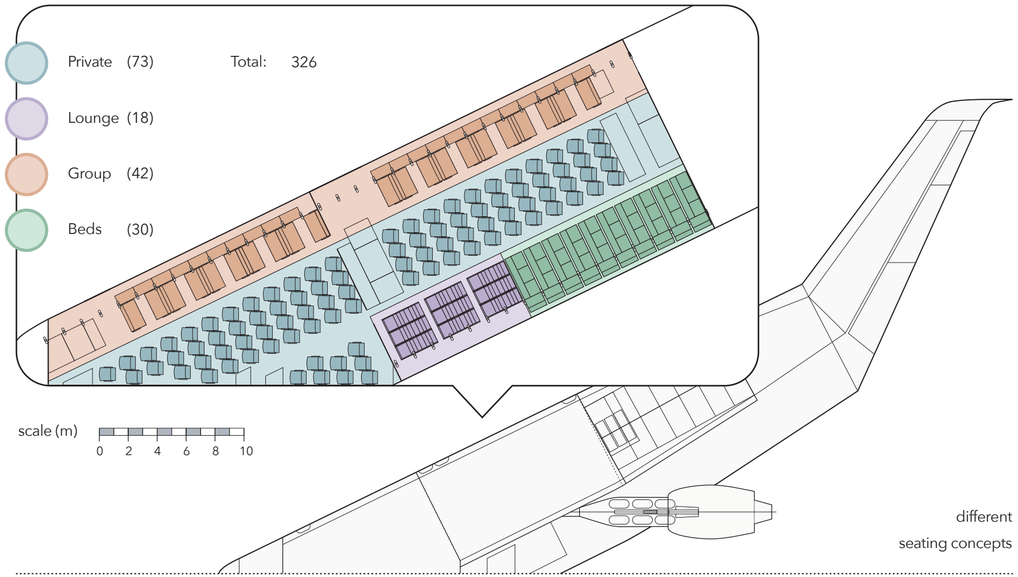


Figure 02-03: Floorplan with different seating concepts (TU Delft, n.d.)

In proceeding floorplan designs passenger seats were angled facing the DOF. In addition, the seats were staggered in order to create aisles and rows that were still parallel and perpendicular to the cabin walls. *(figure 02-03)*. It is noteworthy that it would be possible to angle and stagger the seats less drastically, as long as they are within the 18° limit.

This proceeding floorplan design also incorporated four different seating concepts, including group seats, lounge seats, and beds which could be converted into three seats during take-of. The aim of these seats being that passengers would be able to rotate between different seats during a flight. ▸

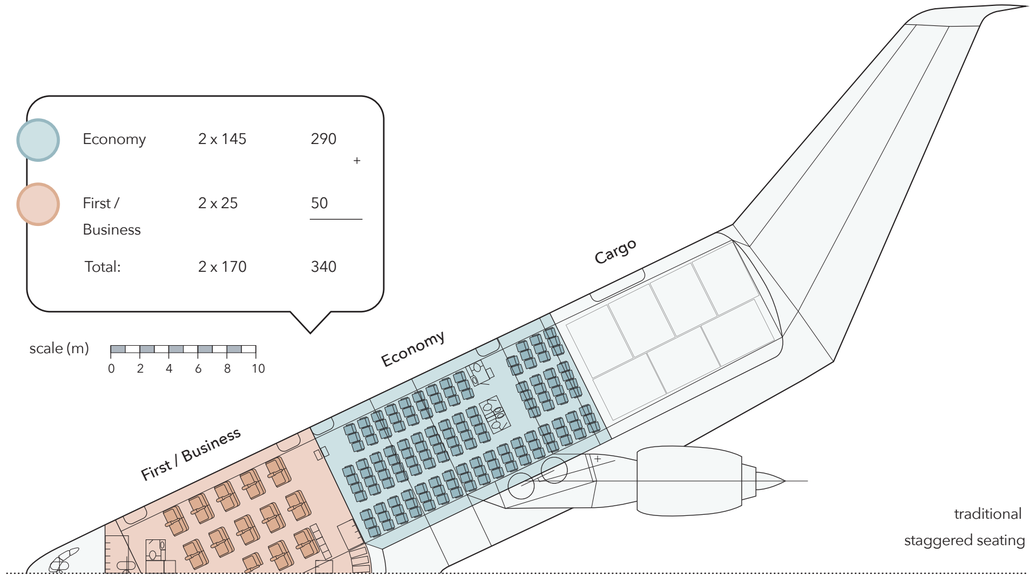


Figure 02-04: Floorplan with minimally staggered seating (R. Vos, personal communications, 15th December 2020)

Additional floorplans were created that incorporate the staggered seating concept to a lesser extent and have a layout that is similar to current floorplan *(figure 02-04)*. (R.Vos, personal communication, 15th December 2020). Noteworthy is that this layout has a more traditional distinction between business and economy class. Additionally, the main galley in the centre of the aircraft is placed along the main walking path, making optimal use of floorspace.

03 / previous seating concepts

Currently, several seating concepts that aim to improve passenger experience for the flying-V already exist. Research by Vink et. al. (2020) describes the development of a hybrid interior containing four different seating concepts that resulted from an ideation session with 80 students from the TU Delft.

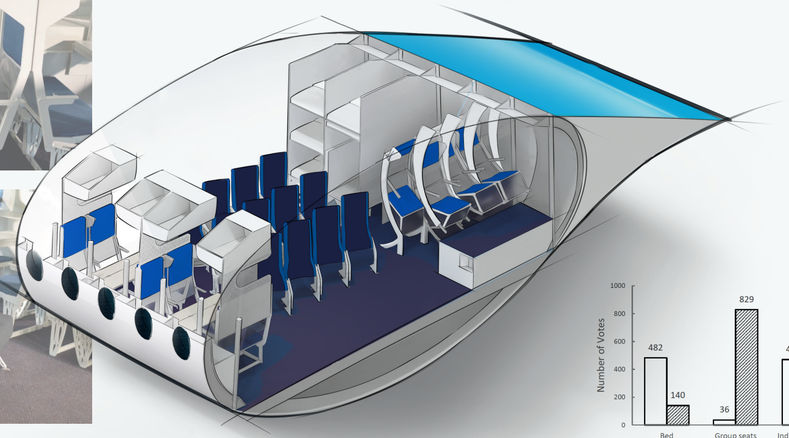
Figure 02-05 gives an overview of these four concepts alongside seat preference of group and individual travellers as described in this research. Additionally strong and weak points for each of the concepts are indicated, which will need to be considered if these concepts are used in the floorplan.

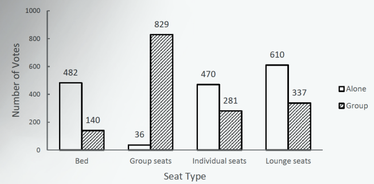
group seats

- Reminded the visitors of train seats
- 12 hours in this position is too much
- Preferably less than 28% should be group space, as there will be flights with only 10% groups.

individual seats

- Appreciated because of shoulder space, armrest, privacy and legroom.
- Passengers putting legs in the aisle might be an issue
- Seat redesign recommended to improve comfort





beds

- Being in the bed for full 12 hours is not preferred
- Eating in this position might be an issue.
- Ingress & egress should be tested

lounge seats

- Appreciated because the body position can be changed.
- Relax position was seen as a benefit.
- Could be a claustrophobic experience when the lower person is sitting upright and the person above will recline.

Figure 02-05 Existing interior seating concepts
(TU Delft (n.d.) and Vink et al. (2020). Towards a hybrid comfortable passenger cabin interior for the flying V aircraft. International Journal of Aviation, Aeronautics, and Aerospace.)

04 / cabin interior - features and geometry

Due to the design of the aircraft and the passenger cabin and wings being integrated, the design of the passenger cabin is altered. This has effect on several aspects of the design, for example the dimensions and geometry of the cabin, the placement of windows, and the placement of pillars and partition walls.

Oval geometry: Width and height

Because the Flying-V's cabin is integrated in the wings, the cabin becomes elliptical. This is different from conventional aircrafts which are most often cylindrical. Nevertheless, the dimensions of the Flying-V are comparable to any wide-body aircraft with a ten-abreast configuration, like the Boeing 747 (6.5 m) or Airbus A380 (7,15 m). *Figure 02-06*, shows the dimensions of the Flying-V's cabin.

Pillars and partition walls

Most aircrafts have a cylindrical fuselage. This is because physics dictates that pressurised structures have a tendency to assume a round shape. Making it the most efficient shape to hold internal pressure. *Figure 02-07* gives an overview of different categories of aircrafts and corresponding cross sections (Schmitt & Gollnick, 2016).

However, because the wings and cabin are integrated in the design of the flying-V, the cabin of the flying-V is oval *(figure 02-06)*. This means that horizontal and vertical pillars are needed to secure structural integrity.

The addition of these pillars has a major effect on the looks and design of the interior of the cabin. The current design contains pillars placed 70 cm apart, with the vertical ones being slightly angled inwards. These pillars create a space of about 40cm between the walls of the cabin and the main area. (TU Delft, n.d.) This space cannot be used for seating, but could possibly be used for luggage storage or other secondary purposes. ▸

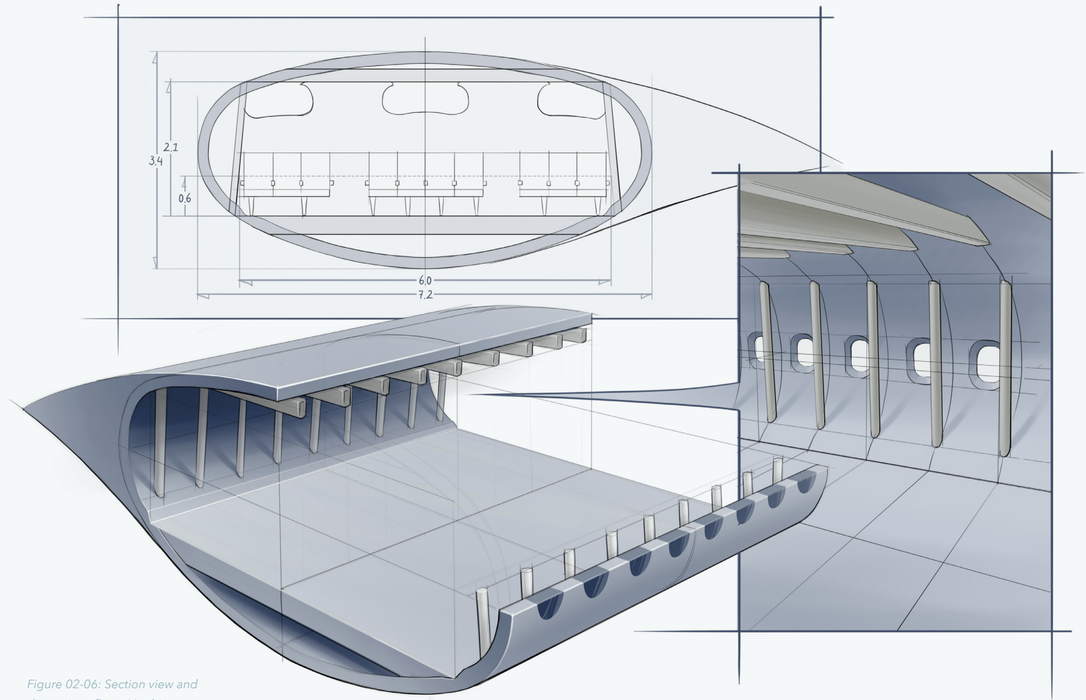


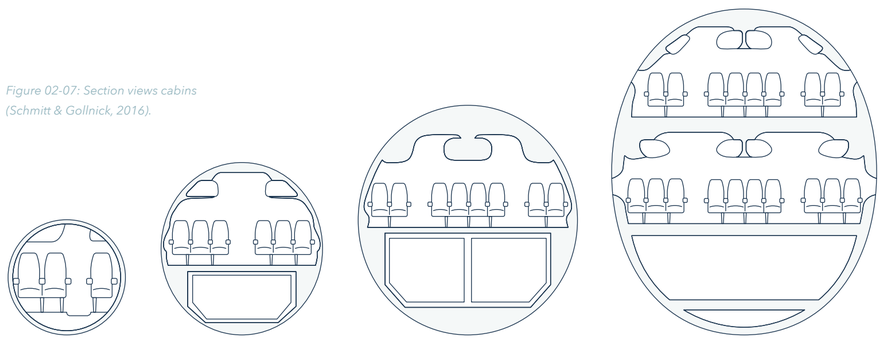
Figure 02-06: Section view and dimensions flying-V cabin

Further structural reinforcements of the fuselage are several bulkheads placed along the cabin. (TU Delft, n.d.) An overview of which can be seen in *figure 02-08*.

Window design

Due to the integration of wing and cabin, windows can only be placed on one side of the cabin. Meaning that less natural daylight can enter the cabin. Due to the low radius of curvature of the side arc, relatively large windows can, however, be placed to partially compensate for this. Additionally, options such as a transparent roof are considered. These features will likely influence the light design of the interior, as well as the placement of seats.

Figure 02-07: Section views cabins (Schmitt & Gollnick, 2016).



commuter
single aisle

narrow- / standardbody
single aisle

widebody
twin aisle

macrobody
double deck

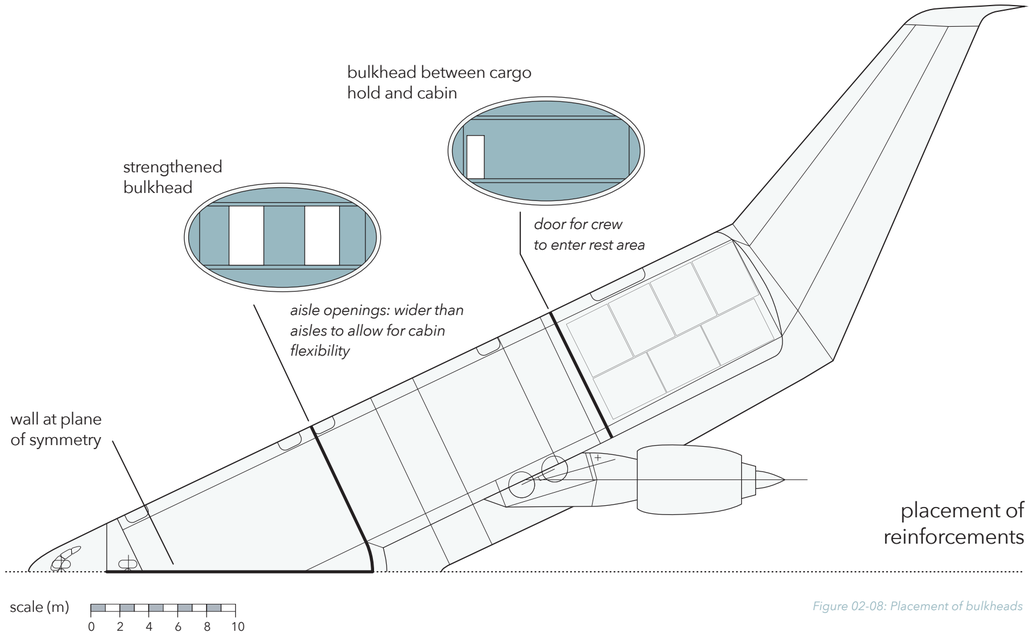


Figure 02-08: Placement of bulkheads

26° DOF angle

One of the main differentiating features of the flying-V are the 26° angled cabins. As mentioned before, this means that seats cannot be placed in rows parallel to the cabin walls. This will have a significant effect on the design of the floorplan of the aircraft. One solution that is utilised in current floorplans, is to stagger the seats so that they are facing the direction of flight. This will allow the aisles between rows to remain parallel to the walls of the cabin.

05 / stakeholders

In order to give insight into which parties need to be involved when designing the floorplan of the Flying-V, a stakeholder overview was created. This overview can be seen in *figure 02-09*. The analysis divides the stakeholders into four categories defined by how much interest and power each of the stakeholders holds. As can be seen, each stakeholder has different functions. The stakeholders that are most relevant to the scope of the project are:

- **Passengers:** passenger interests is high, but has little power over the project. Passenger feedback and ideas with regard to comfort and flight experience will be taken into account during the project.
- **Cabin crew:** low interest, low power. Crew interest in comparison to passenger interest is low, but crew concerns and comfort relating to galley and lavatory placement should be taken into consideration. I.e. their work activities should not be compromised.
- **Aircraft and interior elements manufacturers:** collaboration with these stakeholders is required for acquiring and developing the aircraft and relevant interior elements
- **Airlines:** high interest, high power. Capacity and adaptability of seat and interior elements are the main aspects which need to be taken into consideration to keep airlines interested in the project
- Although important , **any stakeholders that are not directly involved** with the design of the floorplan and interior (e.g. airport crew, maintenance and cleaning companies) will be excluded from the project scope, as its main focus is on the floorplan of the aircraft.

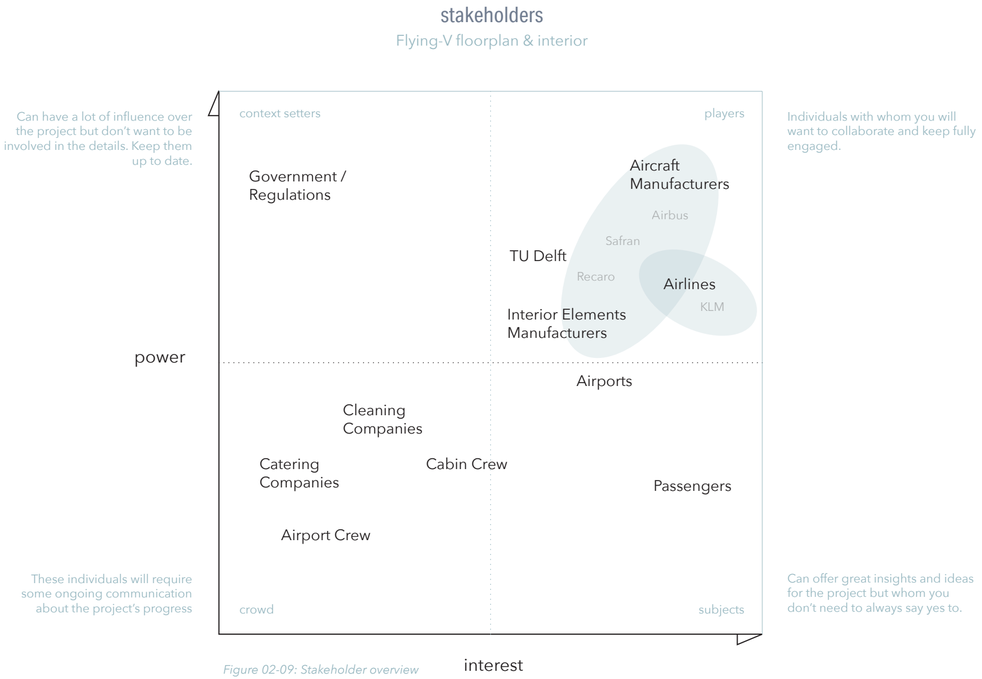
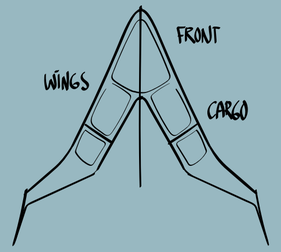


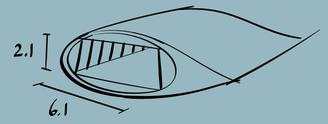
Figure 02-09: Stakeholder overview

take-aways flying-v research

Capacity benchmark
The capacity of the flying-V should be similar to an Airbus A350, which means a minimum capacity of 300 passengers, ideally approaching 350 passengers.

Minimum seating angle
Dictated minimum seating angle has important consequences for passenger seat configurations, as seats cannot be placed along the cabin wall. This means an entirely new approach needs to be taken with regards to placing passenger seats within the floorplan.





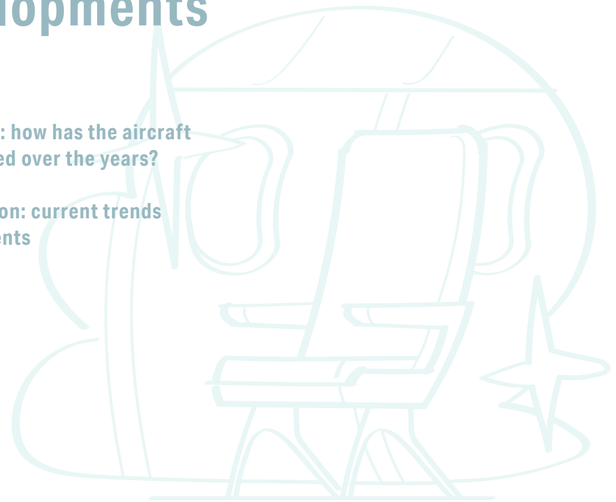
Flying-V layout
The layout has important consequences for floorplan design and passenger experience. The passenger cabin consists of a space at the front and in the two wings. Cargo is placed at the rear of the aircraft. This cargo area is accessible to crew, so crew resting areas or galleys can be placed here. This different layout bring opportunities for placing premium and economy passengers in different areas of the plane: for example placing premium at the front and economy in the wings, or premium in one wing and economy at the front and one wing.

Existing concepts
Several seating concepts such as lounge seats, staggered seats, flatbeds, and group seats already exists and could potentially be integrated into the floorplan.

Cabin geometry
Because the wings and passenger cabin are integrated, the geometry of the cabin differs from conventional fuselages in that's its's oval instead of circular. Furthermore, pillars and beams are placed along the wall and roof (approx. every 70cm), and windows can only be placed on one side of the aircraft.

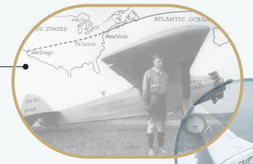
02
02

market studies: trends and developments



01 / short overview: how has the aircraft interior changed over the years?

The experience of flying has developed drastically since the introduction of the first aircrafts in the early 1900's *(figure 02-10 – figure 02-11),* with the Golden Age (1918-1939) defining the beginning of commercial passenger travel by plane and early improvements in passenger comfort and experience. The later Jet Age was defined by the arrival of aircrafts powered by turbine engines, with the Haviland Comet being the world's first production jet airliner in 1952. Further developments made it easier, faster, and cheaper for passengers to fly, resulting in the large aviation economy as we are familiar with today, as is perfectly illustrated by the largest single order of commercial aircrafts today: AirAsia ordering 200 Airbus A320neo jets in 2011. (BBC, 2011)



1908
First passenger flight: Wilbur Wright takes an employee along for a ride

1909
Army Airfield (College Park, Md.) established by W. Wright (longest continuously operating airport)

1910
Orville Wright opens the first commercial flight school in Montgomery, Ala.

1918
National Air Mail service inaugurated, taking over airmail service from the US Army Air Service. This reduced mail delivery time by up to 3 days.

1919
KLM begins operation

1920
International air service between Key West, Florida, and Havana, Cuba offered by Aeromarine West Indies Airways (flying boats).

1927
First ever non-stop (solo) flight across the Atlantic from New York to Paris by Charles A. Lindbergh. This set off a Wall Street rush to invest in aviation, which fueled the development of commercial aviation. Between 1927 and 1929, investments in aviation stocks tripled.

1928
Boeing introduced the three-engine Model 80 biplane, specifically designed for passenger travel. The cabin provided a large inprovement in passenger comfort.

1929
Pan American Airlines inaugurates its first passenger flight from Miami to San Juan by way of Belize and Managua

1930
First female flight attendant, Ellen Church, is hired by Boeing Air Transport (now United Airlines)

1936
Pan American inaugurates passenger flights across the Pacific Ocean

1939
Pan American begins transatlantic passenger service.

The Heinkel He 178 was the first aircraft tot fly under turbojet power.

1950
Transatlantic route is the world's most traveled air route

1952
De Havilland Comet becomes the world's first production commercial jet airliner

1967
The modern-day FAA is established as part of the U.S. Department of Transportation

1968
The first Boeing 737 entered service with Lufthansa.
The 737 became the best-selling commercial aircraft, untill surpassed by the Airbus A320 family in 2019. It however, remains the record for total deliveries.

1986
The Rutan Model 76 Voyager was the first and only plane to fly around the world without refuelling or stopping.

1998
Smoking is banned on all domestic flights

1999
First web-based passenger check-in and online boarding passes

2001
Transportation Security Administration established in response to September 11 attacks

2011
Airbus announces signing of the largest aircraft deal in history based on aircraft ordered: 200 planes ordered by AirAsia

WWI | Golden Age | WWII | Jet Age

1900 | 1910 | 1920 | 1930 | 1940 | 1950 | 1960 | 1970 | 1980 | 1990 | 2000 | 2010 | 2020

1903
Wright Flyer Series were "the first powered, heavier-than-air machine to achieve controlled, sustained flight with a pilot aboard."

1911
Burgess Co. becomes the first licensed commercial aircraft manufacturer

1913
Silas Christofferson carries passengers by hydroplane between San Francisco and Oakland harbors

1914
The St. Petersburg-Tampa Airboat line transported passengers aboard a Benoist Flying boat

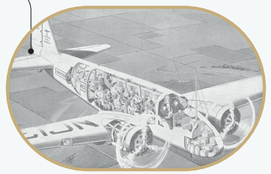
Laurence Sperry invented the steering gyroscope, keeping the aircraft level and traveling in a straight line by itself.

1923
The first nonstop transcontinental flight in the T-2 transport, flying from Roosevelt Field, Long Island, to Rockwell Field, San Diego. This demonstrated the potential of military and commercial aircraft as practical long-distance technologies.

1925
The passage of the Contract Air Mail Act of 1925 diversified the airmail service. Now, the Post Office awarded contracts to private companies allowing them to deliver mail on smaller "feeder" routes that supplemented the transcontinental air route. These individuals would later start many of America's airline giants (e.g. Pan American Airways and American Airlines)

1926
Congress adopts the Air Commerce Act of 1926, which authorized the Secretary of Commerce to designate air routes, develop air navigation systems, and license pilots and aircrafts. These regulations led to improvements in technology, airline safety, and comfort.

1933
United Airlines begins flying coast to coast with a Boeing 247. This 10 passenger aircraft is considered to be the the first aircraft to fully combine advances like all-metal construction, retractable landing gear and a fully cantilivered wing



1935
Boeing designs the 307 Stratoliner, the first commercial aircraft with a pressurized cabin

1940s
Many commercial airlines and airports go offline to commercial traffic to support World War II military efforts

1958
Pan American initiates its New York to London route with the Boeing 707

1959
American Airlines offers first domestic jetliner flights with routes from New York to Los Angeles

1963
The Lear Jet 23 business jet created a new market for fast and efficient business travel.

1973
The first female airline pilot, Emily Warner, flies as second officer for Frontier Airlines.

1976
The Concorde SST jet flies the first supersonic passenger flight.
It is one of the only two supersonic transports to have operated commercially. (Tupolev Tu-144)

1978
Airline Deregulation Act is signed into law, removing government control over fares, routes and market entry

1979
First frequent flier program introduced

1993
First ticketless travel becomes available

1995
Boeing produces twin-engine 777, the first aircraft produced via computer-aided design and engineering

First airline tickets are sold via the Internet

2007
Airbus A380 enters commercial service capable of carrying 850 passengers

2009
Transportation Security Administration formally accepts airport scanners as primary method of pre-flight screening

Figure 02-10: Aviation timeline (Burns & McDonnell, 2011), (Hein, 2019), (Freeman, n.d.), (Falcus, 2016)

early in-flight movie 1925

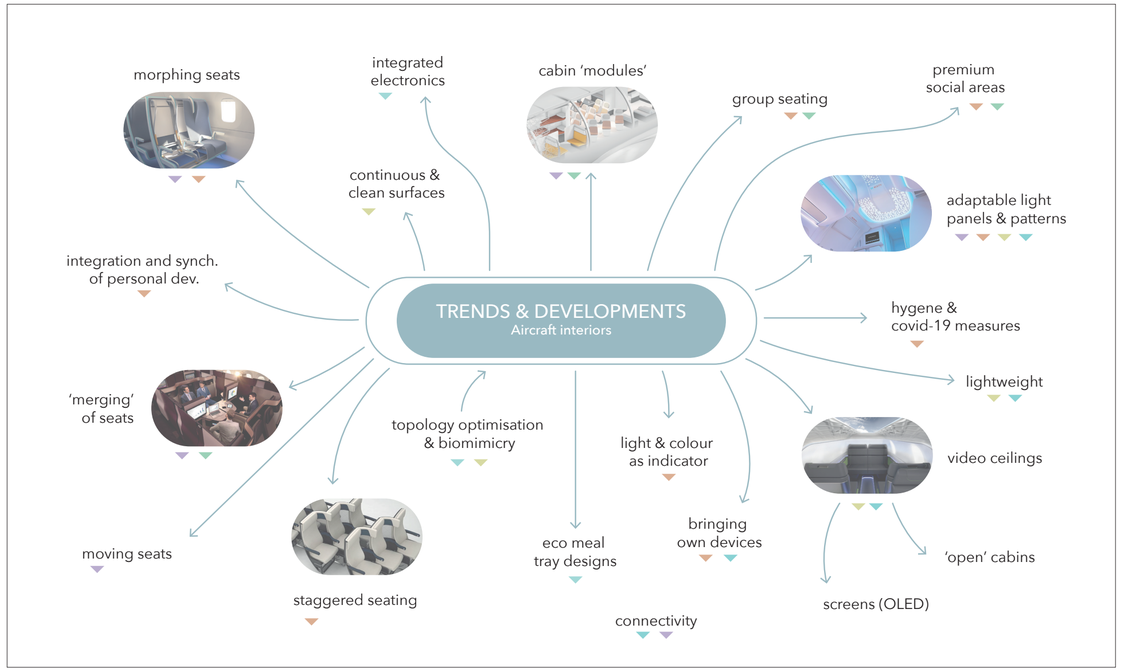
1929

1935

1942

1950s and 1970's

Figure 02-11: Aircraft interiors through the years (various internet sources)



01 / future projection: current trends and evelopments

In order to see which developments and trends with regard to aircraft interior design would still be relevant when the flying-v is introducted, an analysis was made of current trends and developments in this field. Firstly, an inventory was made of concepts of interiors and of interior elements that are being developed or were introduced recently. These concepts were found through several internet sources, using search terms such as: 'aircraft interior concept', 'aircraft seating concept', 'aircraft floorplan design', and 'aircraft interior elements'. All concepts used for this analysis can be found in *appendix A*, alongside a short description of each of the concepts. These concepts were then combined into an overview that can be seen in *figure 02-12*. To further establish more global trends and developments, these concepts were clustered into five different 'themes' *(bottom of figure 02-12 and figures 02-13 – 02-21)* which will be further elaborated on in the following section.

Figure 02-12: Aircraft interior trends and development themes

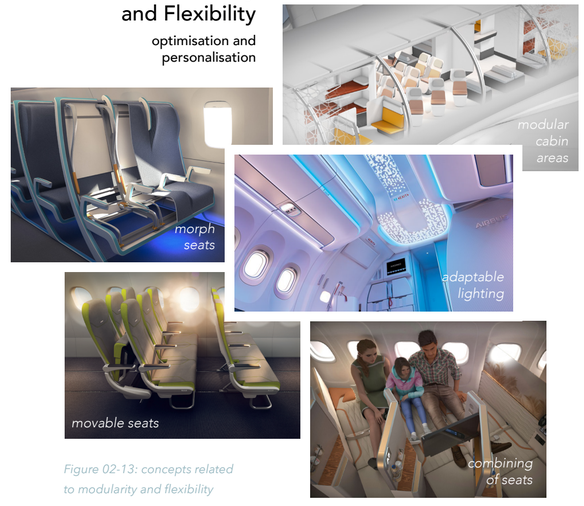


Figure 02-13: concepts related to modularity and flexibility

Figure 02-14:
Airbus transpose concept

Modularity and flexibility

A clear focus can be seen on the design of flexible and modular interiors. This relates to modules that define a larger space of the interior, as well as smaller interior parts, like seats, that are modular and adaptable in itself. This shift can be explained by the desire to optimise the interior of the aircraft for the type of flight (long haul and short haul) and number of passengers.

Concepts are in development that aim to make the complete interior of the aircraft adaptable with the use of large modules, like the Airbus Transpose concept *(figure 02-14)*. The idea behind this concept is to load experience modules into the aircraft, with the intention of reducing the time it takes to reconfigure the aircraft by threefold. (Acubed, Airbus, 2016) This includes areas such as a café, gyms, and children's play areas.

Figure 02-15: PASSME seating concept

Figure 02-16: Flex Seat by Recaro

Additionally, concepts that make the current interior of the aircraft more flexible and adaptable are also being introduced. Most of these concepts are more easily applicable on the short term, because they don't change the design and layout of the complete interior. An example of this is the PASSME seating concept *(figure 02-15)*, which decreases in width during boarding and deboarding, and automatically becomes wider again when passengers are seated. The intend of which is to decrease boarding times and increase passenger comfort thereof (Optimares, 2018).

Seats that move along the aircrafts longitudinal axis are also introduced, like the Recaro's Flex Seat *(figure 02-16)*. When the aircraft is not a full capacity, these seats can be moved back to increase passengers' legroom. Reconfiguring the seat takes less than a minute. (Recaro, 2017). This optimises capacity usage while increases passenger comfort.

Figure 02-17: concepts related to comfort and personal space

Personal space and comfort

Furthermore, concepts are being developed that focus on improving personal space and passenger comfort. This relates to seat design, as well as the design of cabin interior elements such as lighting.

Notably, one of the most visible movements is the use of staggered seating in interior concepts, increasing passengers' sense of personal space. Like Thompson's cosy suite *(figure 02-17, staggered seats)*, which is a staggered seating concept that adds a headrest between the seats for increased seating and sleeping comfort (Marisa, 2015). A combination of staggered and non-staggered seats can be seen in PriestmanGoode's Pure Skies interior concept, taking into account the needs of group travellers by not staggering all seats, still allowing them to talk with each other easily.

More recently, due to the COVID-19 pandemic and its subsequent changes in flying needs and desires, there is a large increase in the development of interior concepts that focus on hygiene and social distancing between passengers.

For example: putting screens between seats separates passengers and decreases the risk of the virus spreading between passengers, while also making people feel more comfortable.

Social spaces

Alongside improvements in personal space, a shift in the design of social spaces or areas can also be seen. This relates to the design of seats for passengers travelling in groups, as well as dedicated social areas.

The previously mentioned Transpose concept includes entire social areas, like café's, bars, and dedicated group seats. This is similar to the more recently introduced social areal called 'The Loft', which is used in Virgin Atlantic's new Airbus A350-1000 aircrafts *(figure 02-18, separate social areas)*. Although not modular, this design offers a dedicated space for premium class passengers to socialise and organise meetings (factorydesign, n.d.).

Figure 02-18: concepts related to social spaces

On the other hand, social area concepts are introduced that can be adapted to either be used for individual travel or travel within groups. Concepts like these also meet the previously mentioned need for more flexibility in the interior. The recently introduced QSuite in Qatar Airways aircrafts ▸

Open Cabin
light and spacious

Figure 02-19: concepts related to the open cabin

for example *(figure 02-18, group travel)*, offers the option to combine seats into a single, double, or quadruple seat configuration, by lowering or placing a panel between the seats. (Qatar Airways, nd. & (Qatar Airways, 2017) A similar concept is proposed by AirGo Design. In this concept called the AirGo Galaxy, privacy walls can be lowered via a two-way authentication system, allowing multiple seats to be combined. This is especially applicable for couple or family travel (Gavine, 2019).

Open cabin

With regard to the spacial perception of the cabin as a whole, a clear shift can be seen towards design that appears light, more spacious, and less cluttered.

Several concepts are being developed and introduced that increase perception of space in the cabin. Concepts like the Heli-X by forakis design *(figure 02-20)* aim to increase the sense of natural daylight in the cabin. Here, a large panel diffuses the light from the smaller aircraft windows, creating one large plane that aims to recreate the sense of one continuous large window (Forakis, 2015).

In other concepts like the Airspace Cabin Vision by Airbus, windows are either entirely or partially omitted and replaced by video screens that project the view of outside onto the cabin wall (Airbus, 2019).

Additionally, as is the case with Airbus' Airspace Interior, adaptable light panels and light patterns can be used to create a sense of space and openness in the cabin, and change the cabins ambience throughout the flight. Furthermore, adaptable lighting can also be used to mimic and steer the natural day and night rhythm to partially decrease passengers' jetlag. (Airbus, n.d.)

To make the cabin appear more calming and less cluttered, continuous surfaces or (partially) open partition walls can often be seen in new interior concepts like the Airbus Airspace Vision, and PriestmanGoode's Pure Skies Concept. This also has an advantage for cleaning purposes, since it creates less spaces where dirt can be trapped.

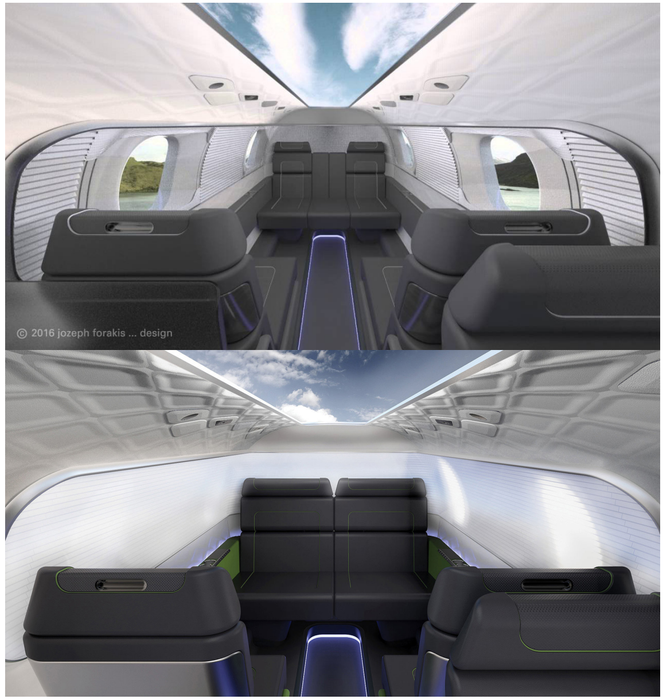


Figure 02-20: Heli-X by horakis design, widow design

Figure 02-21: concepts related to integration of technology

Integration of technology

Furthermore, a push can be seen for the integration of technology and electronics within the cabin and its assembly parts.

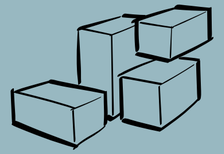
The Lite2Fix concept for example, integrates the cabin's wall panels with an LED display, reducing part count, and increasing assembly through assembly automation. By clicking the LED panel into place, the circuit is closed, simplifying assembly and maintenance. (SFS Aircraft Components)

Additionally, in-mould electronics are being developed to seamlessly integrate electronics within the surfaces of the cabin and its seats *(figure 02-21, in-mould electronics)*. The IME panel by e2ip electronics for example, is an interactive smart surface based on printed electrics, with customisable finishes. (e2ip technologies, n.d.). This makes it possible to further clean up the cabin's surfaces.

Furthermore, some interior concepts also build on the trend of passengers increasingly using their personal devices for in-flight entertainment. PriestmanGoode's Pure Skies concept for example, proposes seats with wireless charging functionality, in addition to device holders for the use of personal and airline devices during flight. (PriestmanGoode, 2020)

take-aways market research

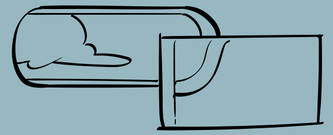
Research into recently introduced interior products and concepts resulted in the following five themes describing current trends and developments with regards to aircraft interiors.



Capacity benchmark
A clear focus can be seen on the design of flexible and modular interiors. This relates to modules that define a larger space of the interior, as well as smaller interior parts, like seats, that are modular and adaptable in itself. This shift can be explained by the desire to optimise the interior of the aircraft for the type of flight (long haul and short haul) and number of passengers on a flight.

Personal space and comfort
Concepts are being introduced that focus on improving individual passengers' personal space and comfort

Social spaces
In addition to individual comfort, comfort of group travellers and social interactions thereof are also taken into consideration through the development and integration of group seating and social areas.



Open Cabin
A clear shift in the design of the interior can be seen towards spaces that appear light and decluttered. Here, lighting and materials are used that create the feeling of a more open cabin environment.

Integration of technology
Taken into consideration is the integration of technology with regards to material usage and assembly. Additionally, airlines and cabin interior designers tap into the trend of passengers bringing and using their own devices on board.

02
03

passenger studies: opportunities to improve

01 / flight activities and comfort and satisfaction levels

During a flight, passengers will experience different levels of positive, and negative emotions, and different comfort levels during different activities.

Research by Bouwens et al. (2017) mapped passengers' emotion level during their flight, and what their comfort levels were when performing different activities. The conclusions of which are summarised in *figure 02-22*.

This research indicates that people generally experience take-off, landing, and meal service as positive, and in-between time, or cruising time, as negative. During this cruising period, passengers perform several activities to pass time. The comfort levels of these activities were also mapped and can be seen in *figure 02-22* as well.

This research showed that sleeping and being bored have significantly low comfort scores. Comfort scores were the highest when food garbage was collected, while passengers were watching IFE, while listening to music and during food service. Comfort scores between short and long haul flights were similar. ▸

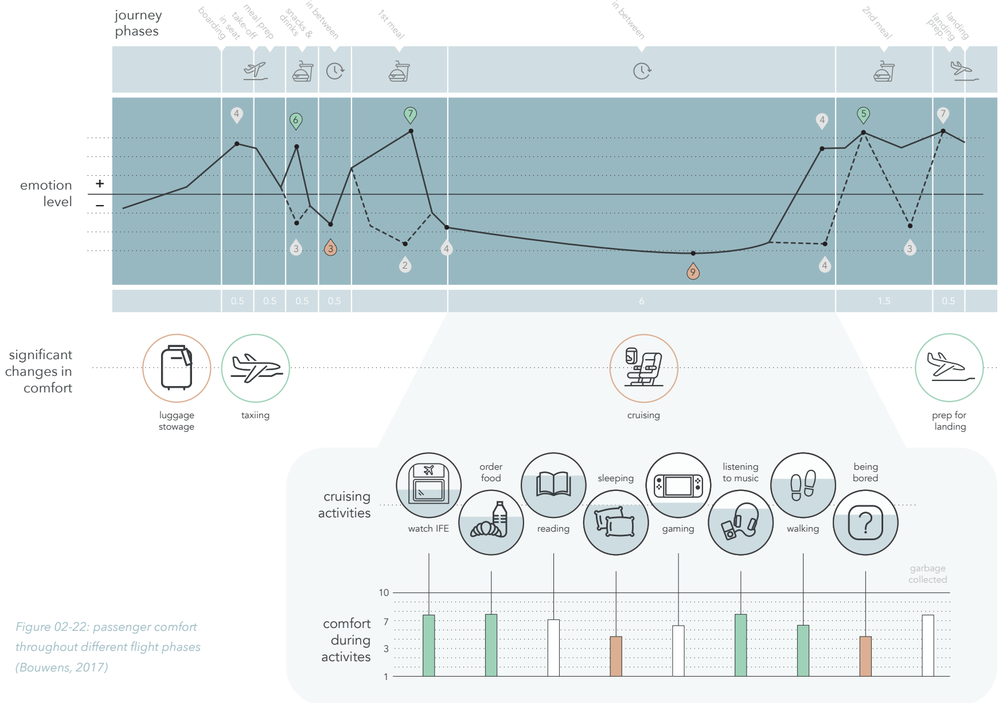
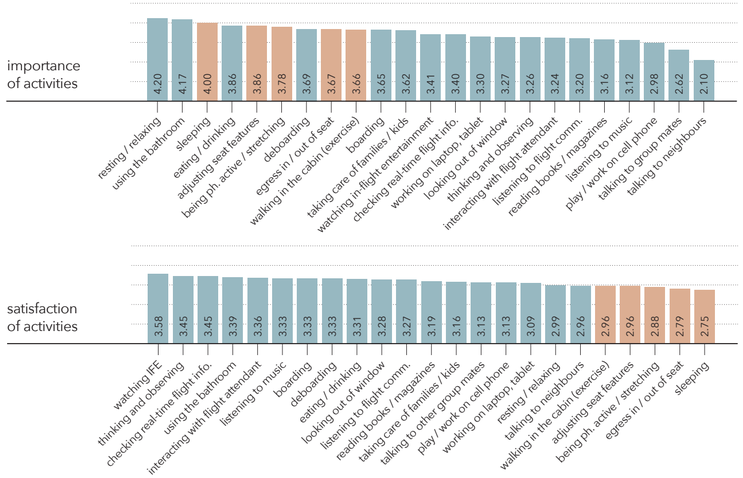


Figure 02-22: passenger comfort throughout different flight phases (Bouwens, 2017)

In addition, research by Torkashvand et al. (2019), mapped the importance of different activities and their satisfaction rate among different types of passengers: individual, couple, and groups. These findings can be seen in *figure 02-23*. Respondents were asked to rate the importance and satisfaction level of each activity on a scale of 1; not at all important / satisfied, to 5; extremely important / satisfied.

Noteworthy is that some activities are deemed important but score low in satisfaction. This indicates that there could be opportunity for improvement in these factors regarding the design of a new floorplan and interior.

As research by Bouwens also indicated, sleeping is considered highly important (4) but scores lowest on satisfaction (2.75). Similarly, being physically active and / or stretching scores low as well (2,88) and is considered relatively important (3.78).



Closely related to this activity is that of walking in the cabin, which is rated comparably. Additionally, activities related to seat design like adjusting the seat's features, and ingress and egress of the seat also score low in satisfaction and high on importance. When activities such as these are improved, passenger experience satisfaction in general will likely improve as well.

Figure 02-23: importance and satifaction levels for different flight activities. (Torkashvand, 2019)

02 / group size and seat preference

Alongside activity importance and satisfaction, Torkashvand's research also analysed seat preference for each of the three types of passengers: individual, couple and group travellers. The five most popular seat configurations were tested (*figure 02-24 and figure 02-25).*

Individual travellers

This research showed that individual travellers most often prefer seats on the window side or the aisle, and the same can be said for couple travellers. Preferences between aisle and window seats in this group only vary slightly, with window seats being preferred slightly more often. *(figure 02-24)*

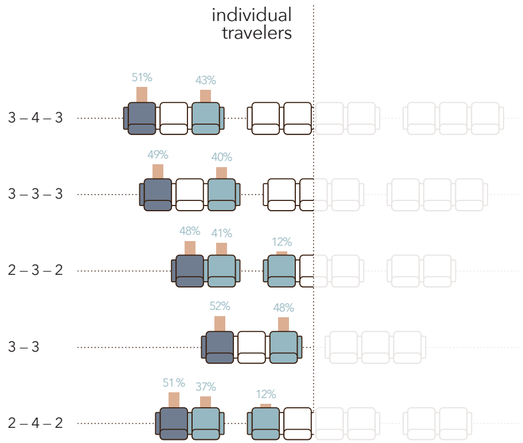


Figure 02-24: individual travellers' seat preference for different configurations (Torkashvand, 2019)

Couple travellers

Couple travellers prefer similar seats to individual travellers. In arrangements of three however, they are willing to choose a middle seat to be able to sit next to each other *(figure 02-25).*

Group travellers

When passengers travel in groups, their main criteria is that they can sit next to each other without an aisle in between. This group as well, prefers window rows above middle rows.

This research shows that different types of travellers prefer different seating arrangements. Opportunity arises for the design of a floorplan and / or seating layout that takes these preferences into account. Variety could be created by for example dividing the layout into different sections for different passenger groups and their preferences. Or by staggering seats in such a way that the layout is divided into smaller sections of 1, 2, or more seats.

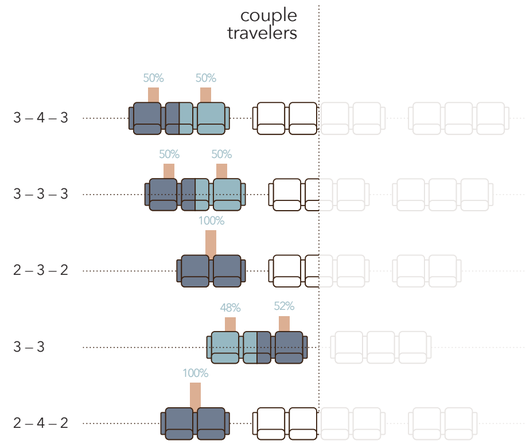


Figure 02-25: couple travellers' seat preference for different configurations (Torkashvand, 2019)

03 / passenger experience research

In order to give more insight into what passengers experience during the different phases of a flight, further research was done into the emotions and experiences of passengers.

Research Setup

An online questionnaire was developed which asked passengers about their emotional response during different phases of a flight. The journey was divided into 5 phases: boarding, take-off, cruising, landing, and deboarding. Cruising was further divided into three different categories: in-seat activities, meal service, and walking or moving about the plane. The complete questionnaire can be found in *appendix B*.

For each of the different phases of flight, scenario sketches were shown to help respondents recall their previous flight experience, making it easier for them to remember their experienced emotions and reasons for experiencing these emotions. *Figure 02-27* gives an overview of which activities were shown in the scenario sketches.

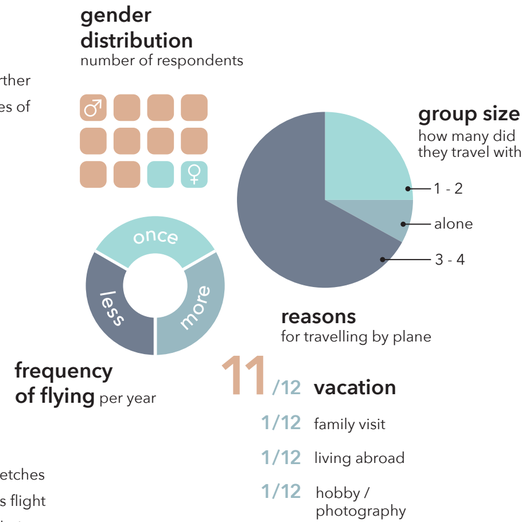


Figure 02-26: general information questionnaire participants

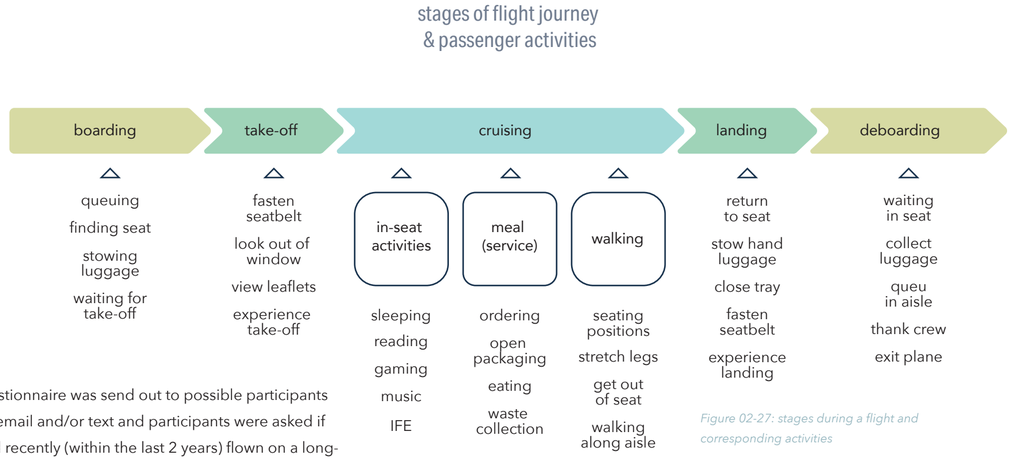


Figure 02-27: stages during a flight and corresponding activities

Results

The questionnaire was send out to possible participants though email and/or text and participants were asked if they had recently (within the last 2 years) flown on a long- or medium-haul flight (>6 hours, and 4-6 hours). In total, 12 people responded to the questionnaire, with ages between 20 and 59. A full report of the results can be found in *appendix C* . All respondents were Dutch, and indicated that they usually travelled economy or premium class.

Noteworthy is that most respondents indicated that they usually travelled with 3-4 people (67%), with the main reason of travel being holiday or vacation *(figure 02-26)*.

The responses for each of the flight phases were extracted from the results and analysed. These statements can be found in *appendix C*. The reasons for the experienced emotions that recurred often are summarised. An overview of each of these responses can be found in *figures 02-28 – 02-35)*, alongside statements that illustrate these responses. In these images green statements indicate positive experiences, and orange negative experiences.

Boarding

The responses to boarding were mainly negative. Passengers experienced boredom due to waiting, uncertainty and hope about what type of passenger would be seated beside them, and anxiety about take-off and the experience of flying. However, the majority (8 Out of 12) also expressed that they were looking forward to their holiday and the journey.

Figure 02-28: boarding activities and experienced emotions

Take-off

Take-off is generally experienced positively. Fascination and excitement were expressed about the process and sensation of the plane taking off, and the passengers indicated admiration towards the technology and capability of flying. Contrarily, some passengers indicated they felt anxious about take-off and the possibility of them feeling nauseous.

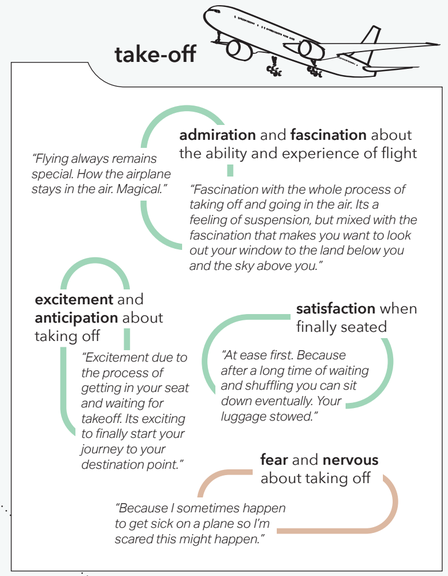


Figure 02-29: take-off activities and experienced emotions

Cruising: in-seat activities

Passengers generally feel relaxed once take-off is over, especially when they were anxious or nervous beforehand. When passengers can entertain themselves with IFE or their own activities, they indicate being relaxed and at ease. However, once they have exhausted these activities, most start to experience boredom.

The main negative emotions during this phase come from being annoyed due to low comfort, the majority of which was indicated due to seating and legroom. Other annoyances were regarding other passengers' behaviour. Respondents indicated getting agitated by for example, passengers unbuckling and moving about immediately after take-off, sitting widely, or their neighbour's screens being too bright.

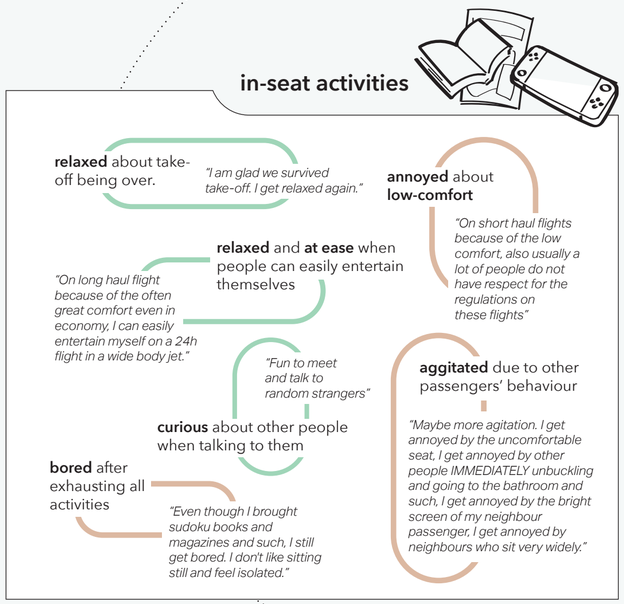
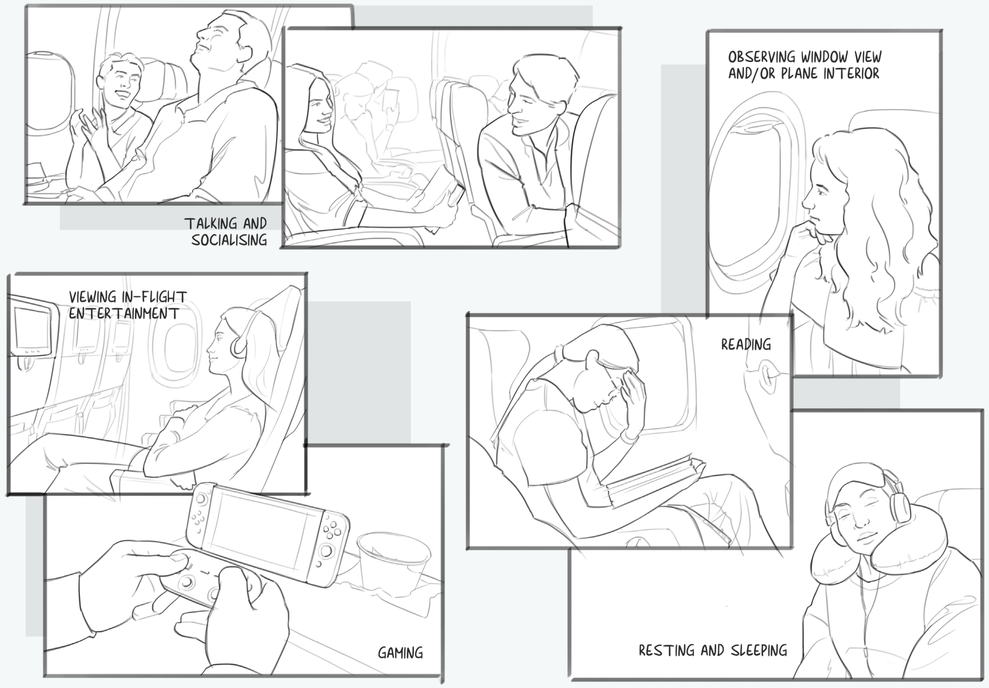


Figure 02-30: cruising (in-seat) activities and experienced emotions



Cruising: meal service

In general meal service was indicated as being a positive experience during the flight. Several respondents indicated that the excitement about getting something to eat is a nice break from being bored during the flight.

They also responded positively about airline meal service being a unique experience, and being curious about what type of food they would receive and how it would be packaged. Prior to receiving the food, they experience feelings of hope and anticipation for something to eat.

Negative emotions, however, arise when passengers don't like the food, as passengers indicated being disappointed or annoyed by this. Additionally, pickup is experienced negatively when this takes too long. In some passengers, feelings of claustrophobia and agitation arose when they couldn't move due to the meal's waste being in the way of them getting up.

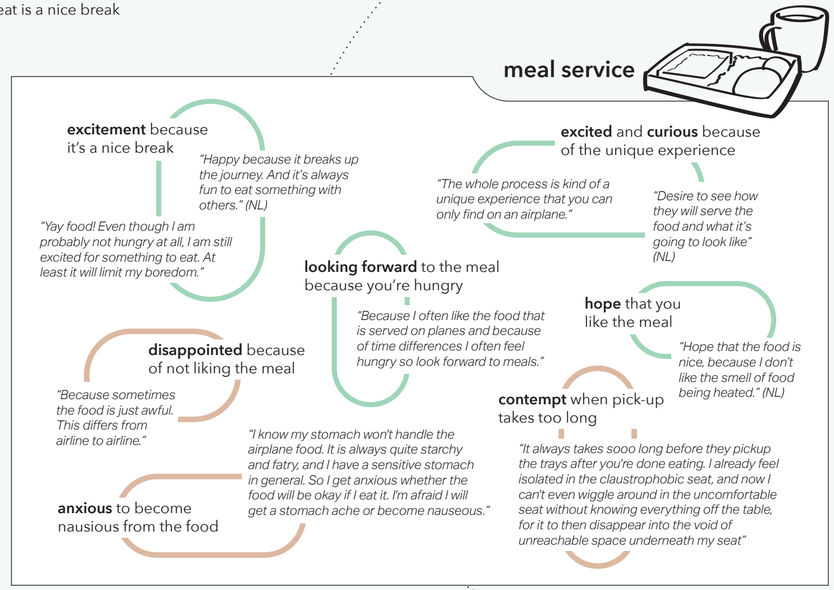
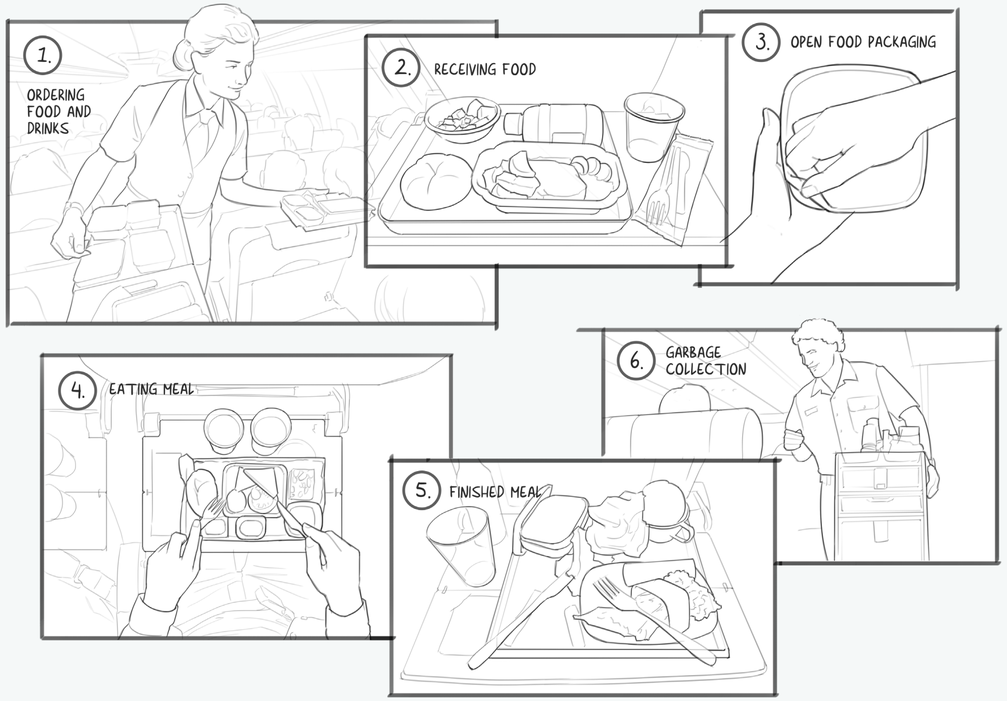


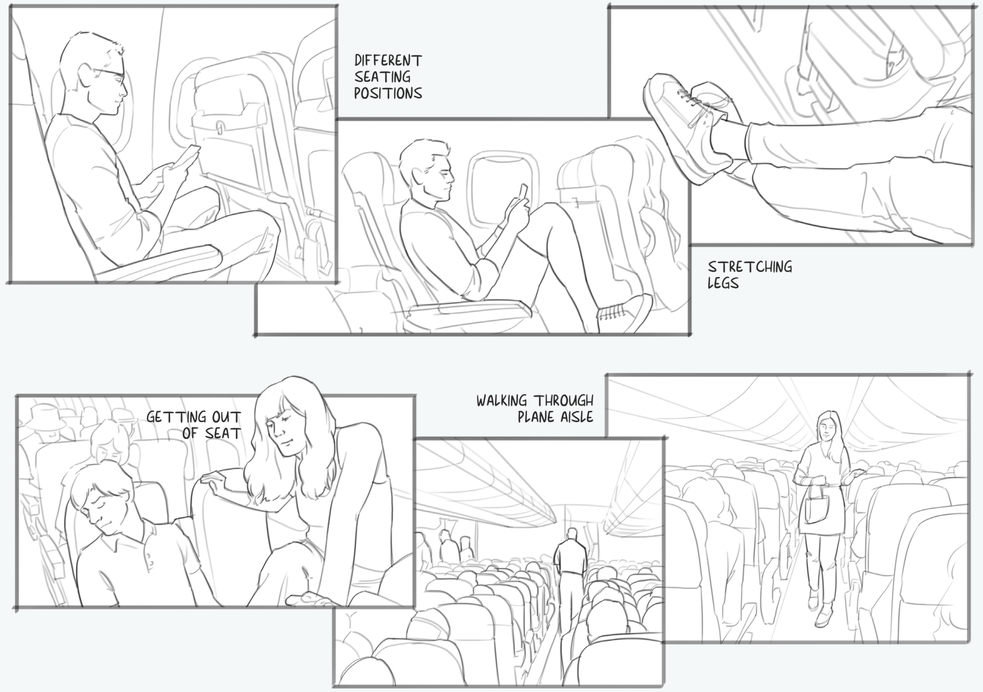
Figure 02-31: cruising (meal service) activities and experienced emotions



Cruising: moving about

Some respondents get frustrated about the limited legroom they have in their seat, especially if they are taller than average. They do respond positively about being able to walk around and stretch their legs. However, they indicate getting hesitant about getting out of their seat because they don't want to disturb and inconvenience other passengers by having to pass by them. On the flipside, they also get annoyed when other passengers disturb them or don't notify them when getting out of their seat. Once walking along the plane, passengers are often disappointed and unimpressed about what they see. Despite some passengers indicating being impressed by the design and capabilities of the aircraft as a whole, most consider what they can see quite boring.

Figure 02-32: cruising (moving about) activities and experienced emotions



Landing

Similar to take-off, passengers experience landing positively. Again, some passengers get anxious and nervous about the landing. Overall, they experience the same fascination and admiration with the sensations of landing as they do with take-off. Alongside, they indicate anticipating and feeling curious about their destination. They are joyful about starting their holiday.

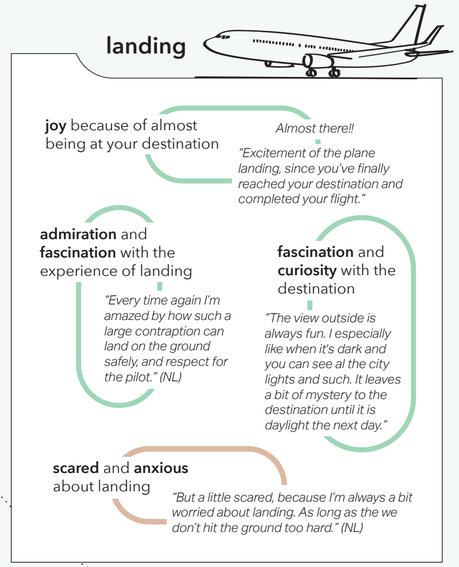
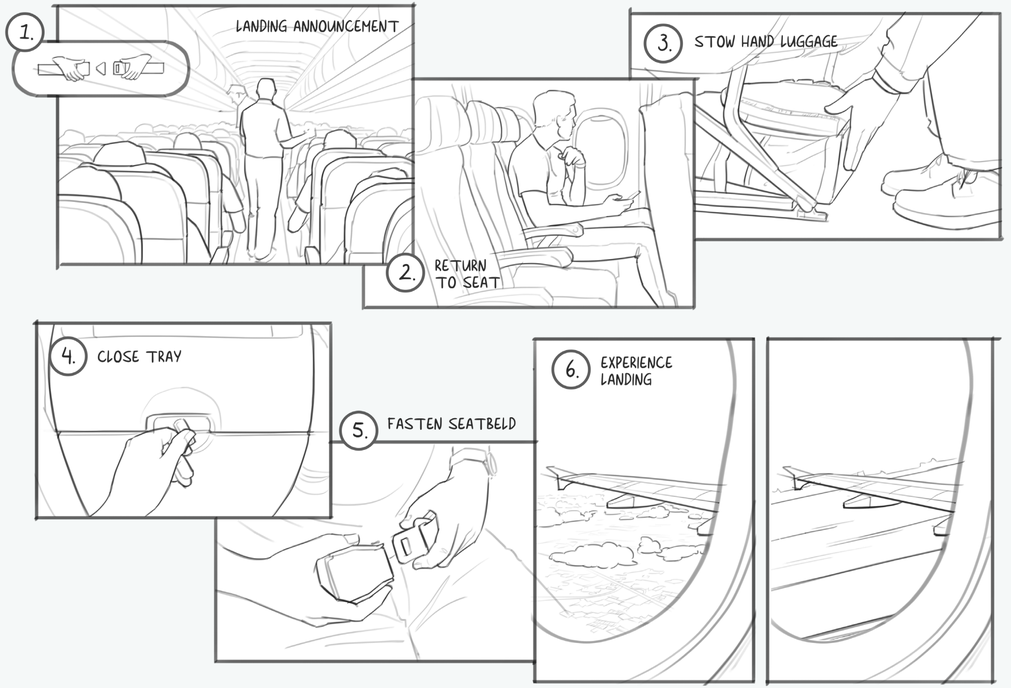


Figure 02-33: landing activities and experienced emotions



De-boarding

The same joy about starting the holiday carries through in the first part of deboarding. However, passengers quickly get annoyed because of other passengers' behaviour when deboarding. The majority of respondents get agitated about passengers immediately unbuckling and queuing in the aisle. When waiting for other passengers they experience boredom and desire to get out of the plane quickly.

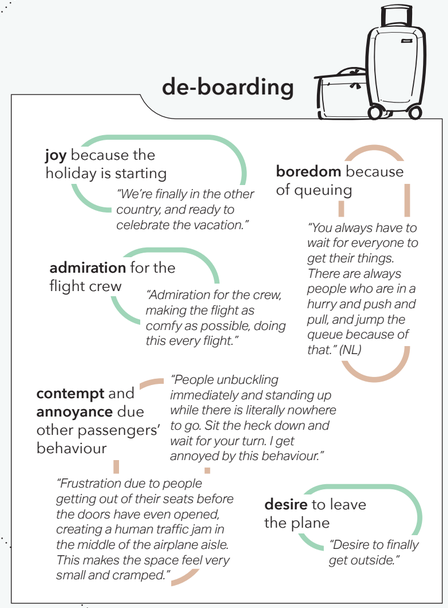
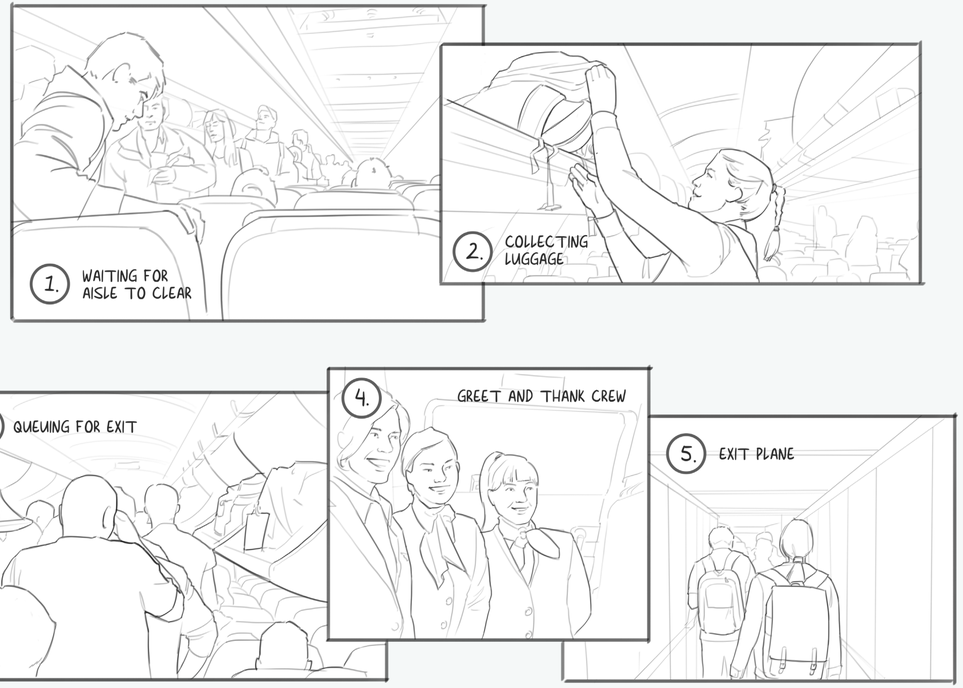


Figure 02-34: deboarding activities and experienced emotions



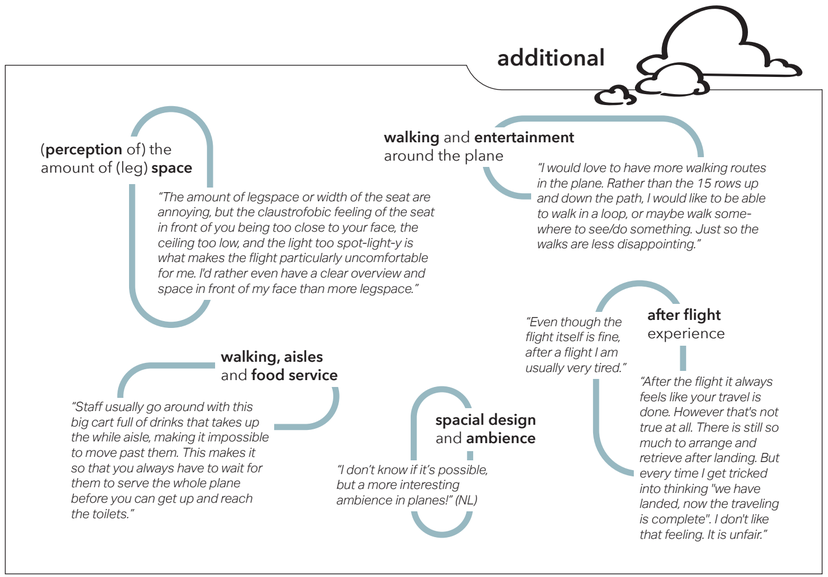


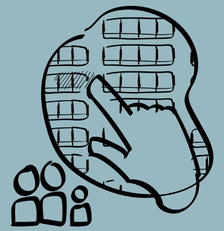
Figure 02-35: additional responses

Additional

Alongside these responses and statements, participants were asked if they had any other points of attention or changes that they'd like to see regarding their flight experience. These can be seen in *figure 02-35*, additional.

take-aways passenger research

Travel group size and seat preference



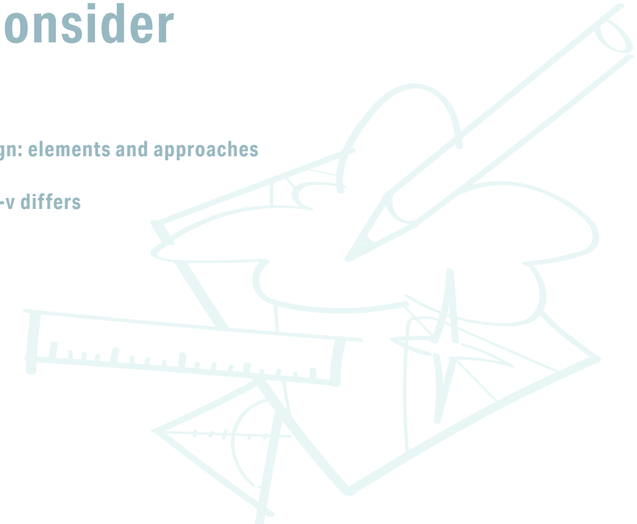
Research indicates that travel group size has influence on seating preference. It was concluded that in general, passengers prefer seating on the window sides of the cabin, with the middle rows being least preferred.
In seating rows of three, Individual travellers prefer the middle seat the least. Group and couple travellers prefer being able to sit next to each other, in which case couple traveller do opt for the middle seat
in rows of three.

Main passenger discomforts and opportunities for improvement.

Five main passenger discomforts were identified that are of interest to tackle when designing the aircrafts floorplan. Research shows that these five aspects score low on passenger comfort but are considered highly important with regard to comfort. Meaning that improvements with regard to these aspects positively affects overall passenger comfort and experience.

02
04

floorplan design: what to consider



Floorplans of several contemporary wide-body aircrafts from different airlines were analysed to determine which aspects to consider when designing a floorplan. These findings where then discussed with Mark Broekhans, Technical Fleet and Arbo Process Engineer at KLM, to supplement these findings and discuss additional points of attention regarding floorplan design.

01 / floorplan design: elements and approaches

From this analysis and discussion, several points that need to be taken into account when designing a floorplan can be formulated.

Placement of galleys and toilets

Wet and dry areas

The main contributor to the placement of galleys and toilets is are the so called ‘wet’ and ‘dry areas’ in an aircraft. These wet areas are the places where electricity and water sources are located for galley and lavatory usage. Additionally, the structure of the aircraft in these places is reinforced, so that it can handle the extra load of galleys and lavatories. The placements of these sources are determined by the aircraft manufacturer prior to the design of a floorplan.

Merging or separation of galley and lavatory areas

Alongside, analysis of current floorplans shows several approaches to the placement and distribution of these galleys and toilets. Noticeable is that certain airlines place lavatories and galleys in the same area, whereas others choose to separate both, as can be seen in *figure 02-36*. Keeping these areas separate has several advantages. Firstly, from a hygienic standpoint, its preferable to separate the two. Secondly, it is more efficient for the flight crew if passengers are kept away from the galleys. Passengers will often wait in the galley when the toilet is occupied, and thus disturb the crew in their activities. ▸

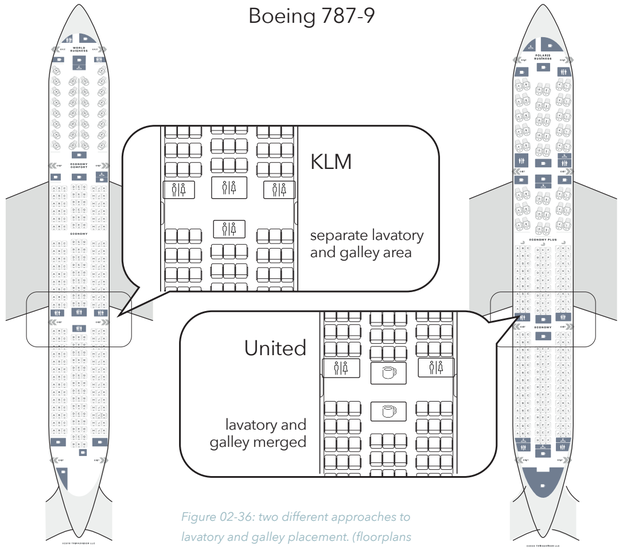


Figure 02-36: two different approaches to lavatory and galley placement. (floorplans obtained from seatguru.com)

Central or distributed placement

Furthermore, the placement of lavatories is also approached in different ways *(figure 02-37)*. Airlines like KLM place a large number of lavatories in one central area of the aircraft. This has the advantage that passengers know where to lavatories can be found. Additionally, there will be less queuing as the result of more available lavatories in one area.

Capacity and distribution of classes

Noteworthy is that distribution of classes is also largely influenced by galley capacity. To optimise space, seating type is often distributed based on how many meals can be placed in galley cabinets. For example, if 6 business class meals can be placed in one trolley, it is more efficient if the amount if business class seats is a multitude of 6.

Furthermore, ideally these galleys are also placed on walking routes to where they should be served to passengers. In other words, business class galleys should be placed next to the business class area, without economy seats in between.

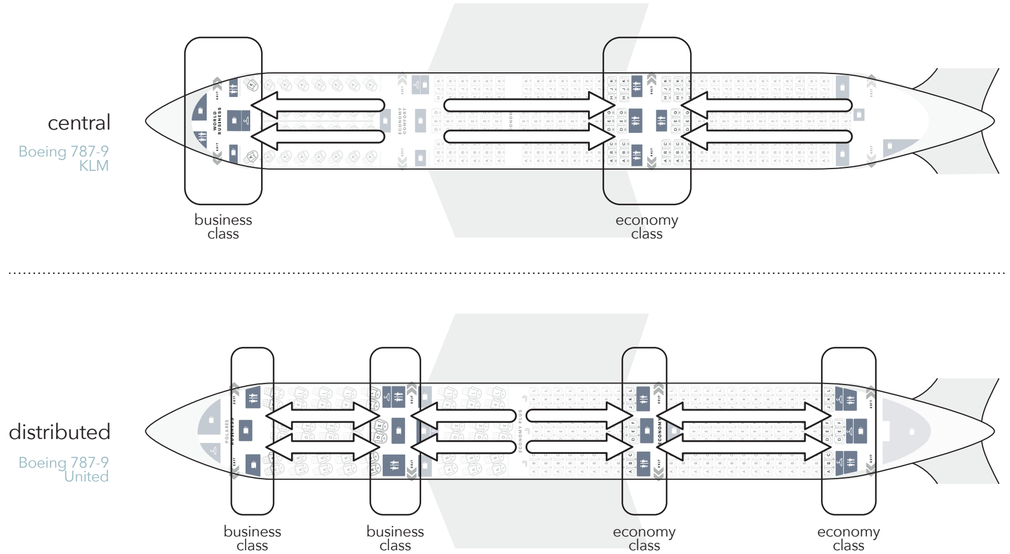
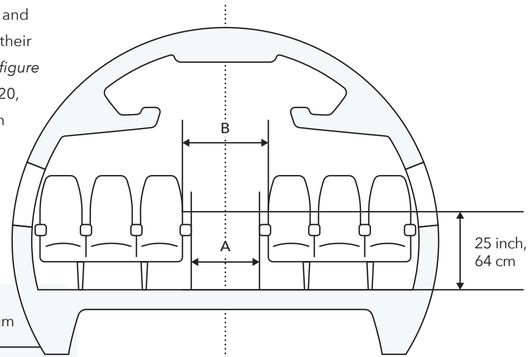


Figure 02-37: central or distributed placement of lavatories (floorplans obtained from seatguru.com)

Capacity and distribution of classes

The FAA specifies different aisle widths depending on the aircrafts capacity, ranging from 15 to 20 inches (38 to 51 cm). (Odukoya, n.d.) These regulations divide aircrafts into three categories: 10 or less passengers, 11-19 passengers, and 20 or more passengers. The different categories and their corresponding minimum aisle width can be found in *figure 02-38*. Since the flying-V has a capacity of more than 20, only the last category is relevant, dictating a minimum aisle width of 381mm below 64 cm height, and 508mm above that.



number of seats	A minumum	B minumum
≤10	12 inch, 305 mm	15 inch, 381 mm
11-19	12 inch, 305 mm	20 inch, 508 mm
≥20	15 inch, 381 mm	20 inch, 508 mm

Figure 02-38: minimum aisle width for different aircrafts (Oduyoka, n.d.)

02 / how the flying-v differs

The flying-V unique layout has consequences for the placement of interior elements such as galley and lavatories, but also on walking and emergency routes, and the placement of different seating classes. Several differences from conventional aircrafts are outlined below. An overview can be seen in *figure 02-39*.

Boarding and walking routes

Because passengers board on one side of the aircraft they have entirely different walking routes to get to their seats. While some passengers are seated on the side of the aircraft they board the plane on, other passengers have a longer walking route to get to their seat at the rear of the other wing. This means that seat numbering and route indications need to be taken into consideration during the design process.

Layout: Two fuselages, large space at front

One main difference between the Flying-V and other aircraft is its unique two-fuselage or two-wing design. This brings interesting opportunities such as dividing the cabin into different sections with each wing serving a different function, since the layout of the aircraft inherently provides division between spaces.

Additionally, the large open space at the front has entirely different dimensions than conventional fuselages. This means that placing seating in conventional arrangements might not be ideal. Here the question arises how different elements in the space can be arranged without creating much empty, unused space.

Cargo placement

In normal passenger planes, the cargo is placed below the passengers. However, this is not possible in the Flying-V due to the its oval fuselage. Alternatively, cargo in this aircraft is placed at the rear of the aircraft. This means that it is accessible for crew, allowing for, for example, the crew resting area to be placed here.

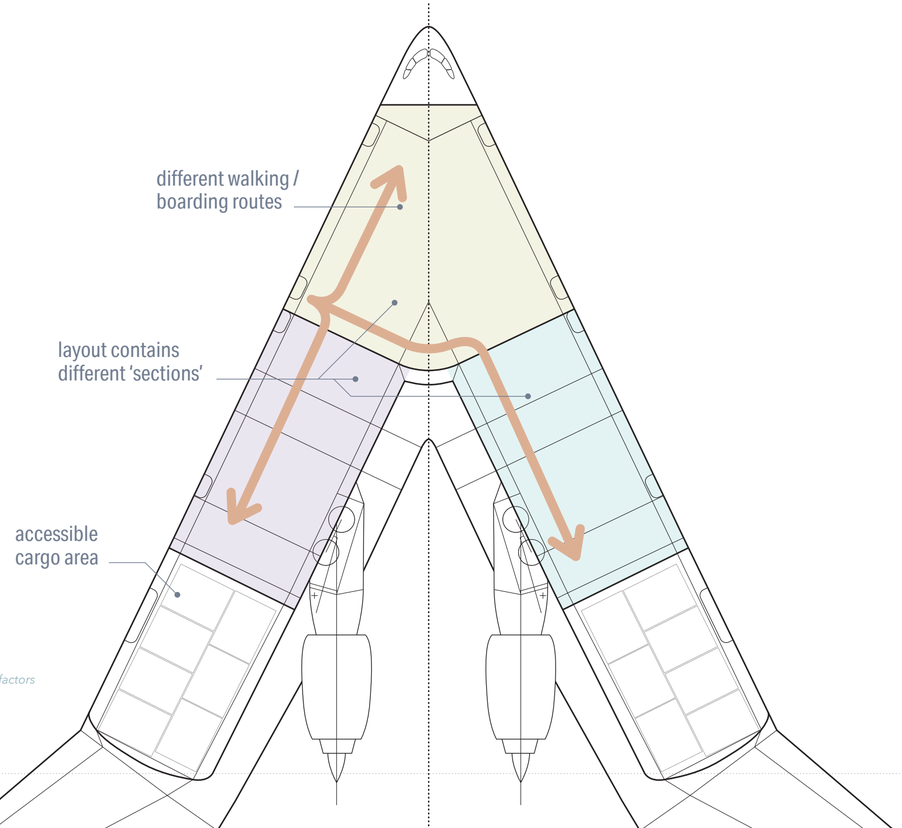
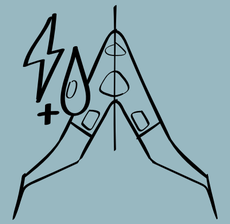


Figure 02-39: main differentiating factors relating to the flying v's layout

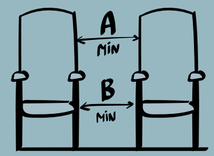
take-aways floorplan research

Wet and dry-areas
Areas of the aircraft that have access to water and electricity.



Different approaches to galley and lavatory placement
Placement of galleys and lavatories can be central or distributed and galley and lavatory areas can be merged or separated.

Effect of galley capacity on distribution of travel classes
Airline cart capacity has influence on how many passenger are placed in each travel class (economy vs. premium). To most efficiently use galley and cart space, the amount of seats in a travel class should ideally be a multitude of the amount of meals that fit into an airline cart



Minimum aisle widths
Regulations dictate the minimum aisle width at two heights, depending on the number of passengers on board of an aircraft. Aircrafts with more than 20 passengers require a minimum aisle width of 381 mm below 640mm height, and 508mm above that height.

03
00

design goal

from design directions to design goal

/ 01 ideation

/ 02 design directions

/ 03 direction assessment and choice

/ 04 design goal

03 01

ideation towards design directions

01 / approach

In order to define a design goal, several design directions were first explored. These design directions solve several problems relating to passenger comfort and/or exploit other opportunities that were concluded in the research phase. An overview of how working towards these design directions was approached can be seen in *figure 03-01*.

The ideation of different design directions was split into two phases. Firstly, several design directions were formulated using how-to's and search areas, utilising conclusions from the research phase. (Ideation I)

Secondly, ideation was done with the floorplan and interior elements as a basis (ideation II). Some of the design directions in this ideation phase elaborated on ideas resulting the first ideation, while others arose during floorplan ideation. Together, this resulted in four different design directions.

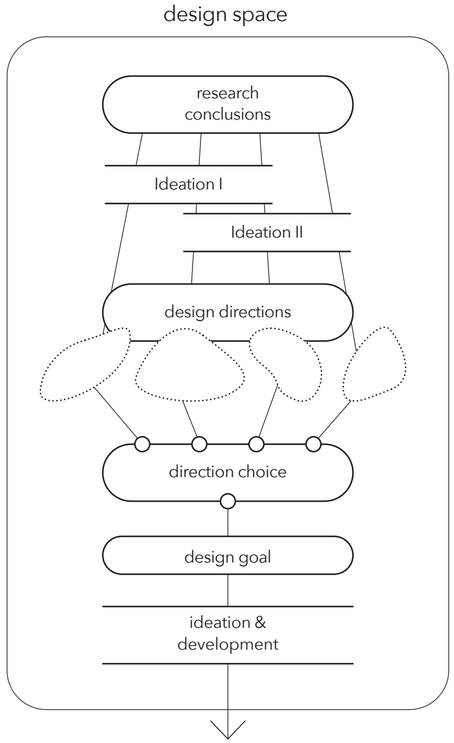


Figure 03-01: design process: from research conclusions to design goal

02 / ideation I: search areas and how to's

The conclusions from the initial research as described in *chapter 2* were the starting point for the first ideation phase. A summarised overview of the conclusions used can be seen in *figure 03-02*.

Using these conclusions, several solutions and opportunities for layout and interior design elements were ideated using the 'how to' and search area methods. Some ideas herein focussed more on overall floorplan design, where others were smaller and more practical solutions that could potentially be integrated into the different design directions.

Several ideas that arose from this ideation phase can be seen in *figure 03-03* (how to's), and *figure 03-04* (search areas). ▸

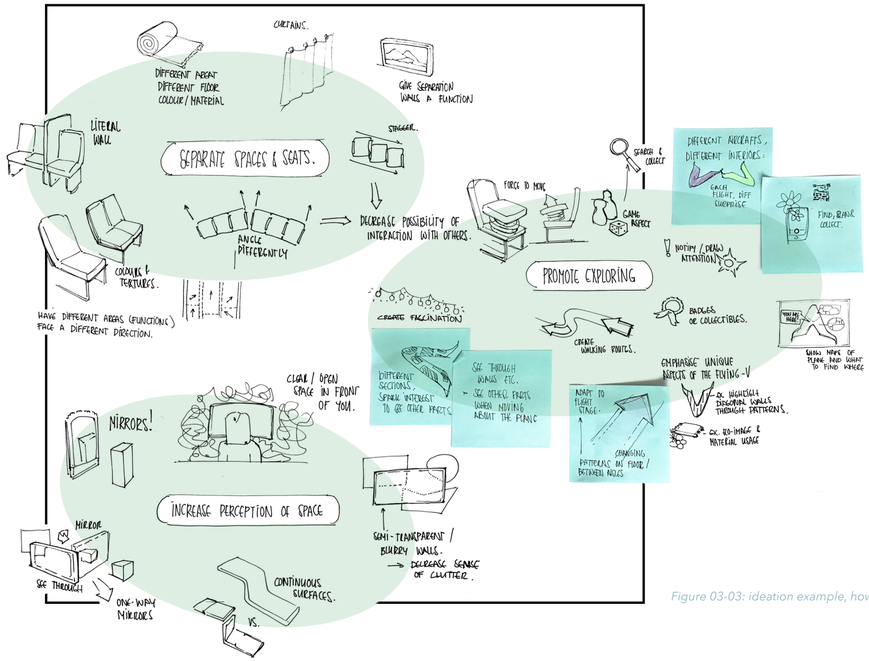


Figure 03-03: ideation example, how-to's

flying - v
opportunities & limitations

- pillars create space between walls and seat and can obstruct window view
- large space at front of aircraft
- 20% more efficient
- cabin walls and windows at an angle
- windows located only on outer side
- passengers board on one side of the plane
- oval cabin shape
- passengers can't see wings, engine and steering mechanisms

passenger
needs & wishes

- improved ingress & egress
- desire to sleep more comfortably
- more legspace or perception thereof
- limite boredom with things to see and/or things to do
- more personal space & privacy
- travel and sit within your own group
- desire to stretch legs and move around

context & market developments

- seating:
  staggered seats
  moveable seats
  merging of spaces & seats
- open structures:
  transparency and lighting
  topology optimisations
- capacity: more passengers, less space
- integration of virtual world:
  video windows, flight information, personal devices
- social or other dedicated areas
- different passengers, different activities

Figure 03-02: main research conclusions

The axes for the search area method were based on conclusions from the research phase mentioned above. Here the points on the vertical axis or so called internal opportunities, are unique characteristics of the flying-v that could be exploited and emphasised *(figure 03-02, column 1),* and ones on the horizontal axis, external opportunities, represent passenger needs and wishes, and context and market developments *(figure 03-02, columns 2 and 3).*

internal \ external	people are bored during cruising	people enjoy take-off and landing	people want to stretch their legs	food = entertaining	people want to sit in their travel group	market trend: less space, more capacity	flying has a bad (ecological) reputations
large open space at the front	entertainment space: to do or to see 03		walk a circle around the plane, or around the front. 03	turn front into 'food and drink hall'.	create group hubs at the front.	more space to stagger seats, less chance of creating 'empty spaces'.	
angled walls and windows	entertainment walls & windows: virtual screens or games	make front view of aircraft visible during landing and flight	walking routes that are not straight but angled differently.		utilise angle to create group seats	utilise empty space created by 26° angle (storage, privacy)	
whole new aircraft design (novelty)	new layout as entertaining factor	take-off is experienced differently (angle)	give people things to see!	make food or other service unique to flying-v	make choosing the seats prior to flight more engaging	opportunity to focus on sth else than other aircrafts (e.g. privacy, legspace)	enhance eco-friendly image: what makes it different
passengers board on one side of the plane	interesting boarding route, each wing different layout		make different areas visible along the boarding route.	show where the food comes from and how it's prepared	people see other seating arrangements when walking		
windows only located on one side of the plane	window facing seats, turn empty wall into entertainment wall	make take-off & landing enjoyable on windowless side, anticipate landing	make the empty walls something interesting to look at		make wall something to (physically) interact with	interactive wall / window to the other side of the plane 01	turn empty wall into 'green walls'
aircraft is 20% more efficient			power something by walking around	meal and packaging bio-friendly materials (biodegradable).		more efficient, so maybe capacity can be slightly less of a financial concern	
pillars and space between seat and walls	give pillars a secondary function	move (a projection of) the window closer to the seats 01	different seat for space between pillars and wall 02	food conveyor belt! like sushi bars	walls between the pillar and the wall to separate the rows from each other	use empty space for something: luggage, table, secondary seating	
window view is not obstructed by wings		improve anticipation of landing (show horizon for example)		eat in front of window, extent / project view on the seat in front 01			
passengers can't see engine & flying technology	show information about the engine & flying technology.	pass the sound of the engine through to the cabin, enhance experience.	show technology at the places where they are located in the cabin		group games with flying technology		incorporate new technologies enhance scale and magnitude of aircraft

Figure 03-04: ideation example, search areas (1/2)

external ↓ internal	people want to sleep more comfortably	people want more privacy & don't want to disturb others	people want more comfortable ingress & egress	people want more legspace	some people require more legspace than others	different people want to perform different activities
large open space at the front	reduce noice from other passengers in this large space		larger, so more space to play with different configurations		more variations in legspace & corresponding price	have designated areas for different activities
angled walls and windows		make triangular corners facing the wall for privacy	rows of seats along the wall instead of perpendicular to it 04	configure so that unused space can be utilised somehow (as legspace)		
whole new aircraft design (novelty)			layout based on different types of comfort (e.g privacy, legspace)		use aircrafts uniqueness as an opportunity to improve comfort	
passengers board on one side of the plane	sleeping hubs at points where people don't pass by often	make sure people don't disturb others when they walk by	improve ease of finding route & seat 05	place seats facing the aisles so that they become legspace during flight 04		
windows only located on one side of the plane	darker, which means better area for sleeping	turn windowless side of the plane into 'quiet side'			swap one comfort for the other (e.g. window side; light & other side; legspace)	
aircraft is 20% more efficient						
pillars and space between seat and walls	use extra space to create bed or more sitting / lying area 02	use space for sound isolation	aisle on window side, like train	turn the extra space into legspace.	turn this seat into 'extra legspace' seat, possibly for a higher price	use space between pillars as work space
window view is not obstructed by wings			aisle on window side 04			
passengers can't see engine & flying technology						

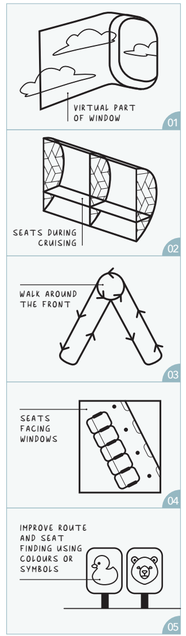


Figure 03-04: ideation example, search areas (2/2)

03 / ideation II: floorplan exploration

Secondly, the empty floorplan of the Flying-V was used for further exploration and refinement of the design directions formulated during the first ideation phase, in addition to producing an additional design direction.

Limitations & constraints

It is worth mentioning several constrains and limitations relating to the floorplan used during this ideation phase, as not all details of the design or regulatory restrictions relating to safety and interior element placement were known and/or yet relevant at this point. On overview hereof can be seen in *figure 03-05*.

Pillars

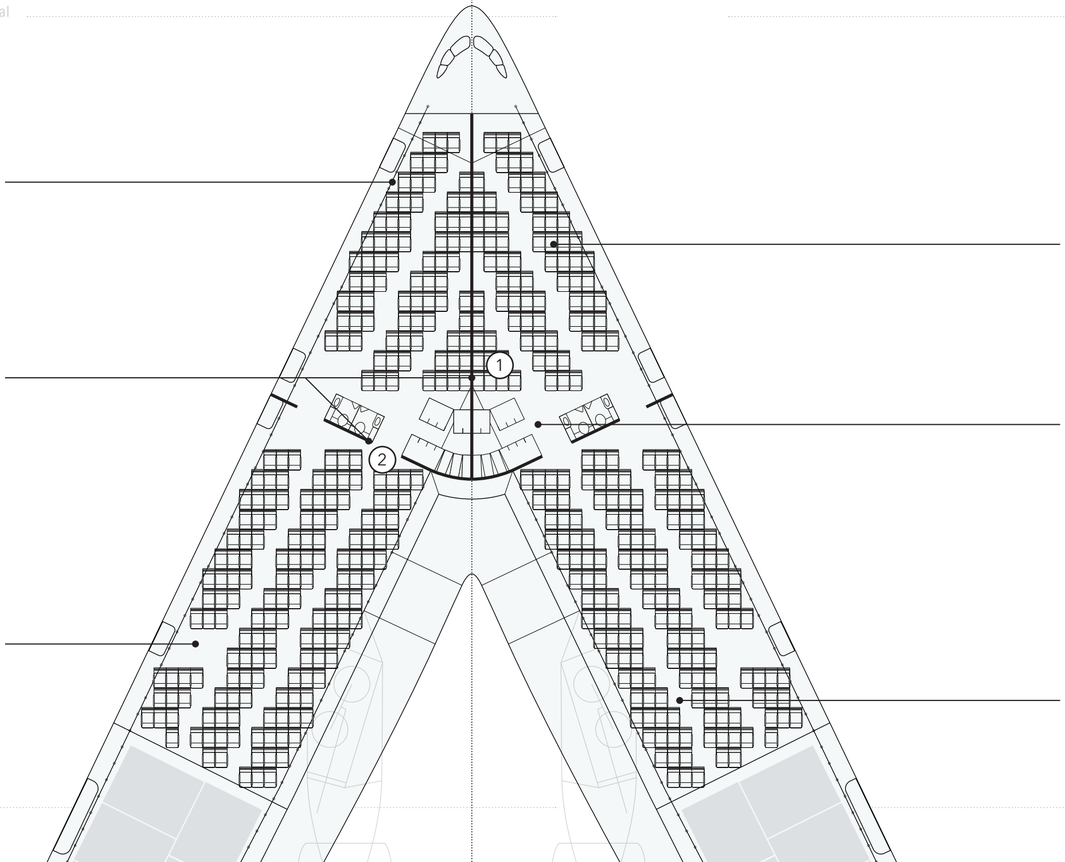
Firstly, the exact placement of the pillars was not yet known. The space between the pillars (70 cm) and the general location however were, so these were incorporated in the floorplan.

Partition walls

Current floorplans of the Flying-V contain a partition wall between the cabin wings and the space at the front (2), and on the line of symmetry in the front space (1). Where necessary, e.g. when an aisle passes through the wall, passageways where added. Additionally, in some floorplan ideas, the wall between wing and front space (2) was moved slightly to support the concept.

Emergency Exits

The initial placement of emergency exits as indicated in current floorplans was used, however, these are subject to change during further development.



Seating angles

Regulations by the FAA dictate a maximum variation from the DOF of 18°. These maximum angles were used during ideation, however further regulations regarding reversed seating were not yet considered in detail.

Galleys and Lavatories

The number of galleys and lavatories, and dimensions thereof were based on the frequency and location, and dimensions seen in current floorplans of the Flying-V. These are likely to change during further development. Thus, in the floorplans resulting from this ideation phase, the amount and placement of these elements are only an indication of possible placement. Additionally, the dimensions of possible galleys and lavatories will be defined in more detail during later stages.

Aisle width

FAA regulations state a minimum aisle width of 381mm (15") below 64 cm height, and 508mm (20") above that, for aircrafts with more than 20 passengers. For this ideation, an aisle width between those values - 17" (or 43 cm) - was used for ease and speed of placement.

Figure 03-05: constraints and limitation used during ideation

Seating and aisle configurations

During ideation, several possibilities were explored regarding seating and aisle placement and orientation, staggering of seats, and possible uses of unused space. An overview of these possibilities can be seen in *figure 03-07 to figure 03-09*.

Seating orientations

All possible seating angles within the 18° dictated regulations were explored. Seats can be oriented 18° facing DOF, as well as 18° facing away from DOF at maximum values.

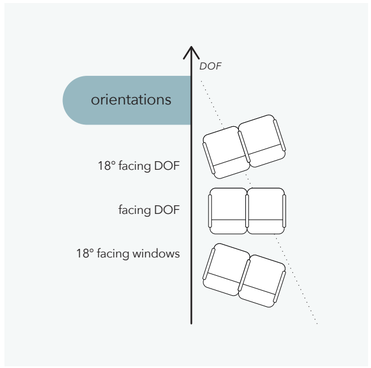


Figure 03-06: possible seating orientations

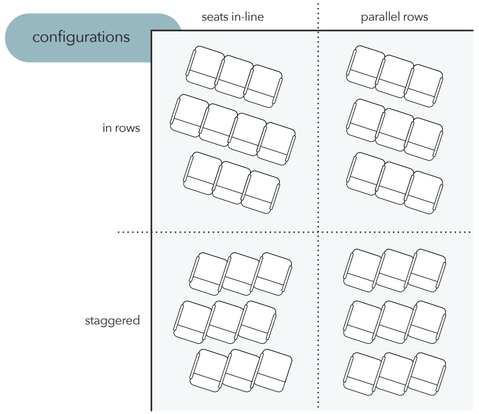


Figure 03-07: possible seating configurations

Seat configurations

Due to the seat orientation restrictions, seats will be configured differently than in conventional aircrafts. This can be done in four different ways. Rows can be angled in their entirety, or individual seats can be rotated, or staggered. Furthermore, seats can then be placed in-line, so that seats will have the same amount of legs pace across their width; or rows can be placed parallel, resulting in unequal leg space.

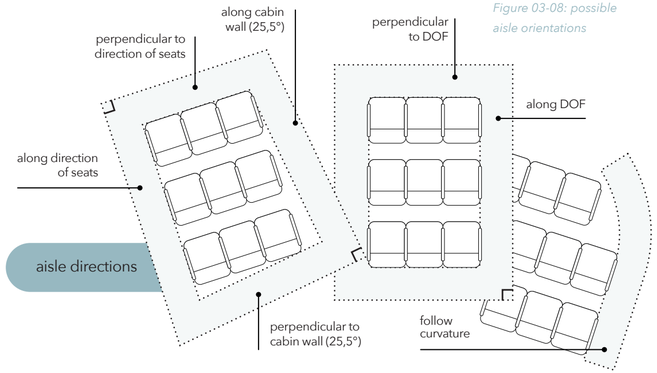


Figure 03-08: possible aisle orientations

Possibilities of unused spaces

Unused space in the layout could potentially be used for different functions. Larger spaces for example might be used for galleys or luggage storage (the space between pillars and cabin wall for example), while smaller spaces that cannot be used for primary seating, can be used as additional legroom or sitting space or in some cases for secondary seating during cruising. Smaller sections could be used as table space or storage of smaller luggage or items.

Aisle orientations

In addition to seat orientations, aisles can be oriented in varying ways. Aisles can be placed parallel to the cabin's wall, the direction of seats, or to the direction of flight.

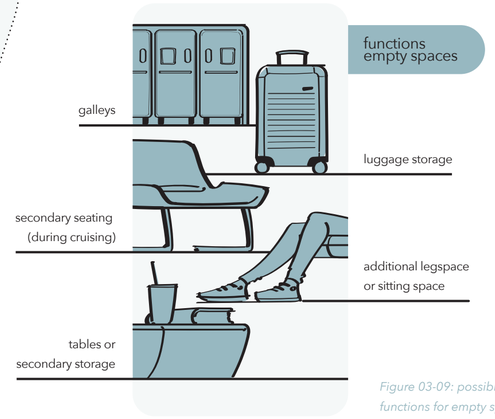


Figure 03-09: possible functions for empty spaces

03 02

design directions

01 / design directions

Each design direction resulting from the two ideation phases explores different opportunities or passenger needs or discomforts, while aiming to utilise unique characteristics or features of the Flying-V. The following figures explain four different design directions resulting from the two ideation phases *(figure 03-10 – 03-13)*.

02 / capacities

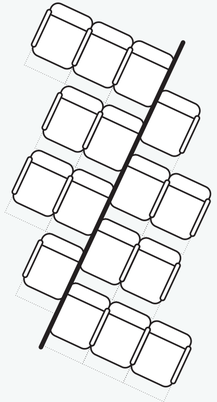
For each of the proposed design directions its capacity was calculated. These values can be found in *figures 02-14 – 02-17*. Noteworthy is that not all capacities are directly comparable, since some concepts contain premium seating, reducing capacity, while others do not. Where possible, capacities without premium seats were also calculated. For example in the second design direction: promote exploring.

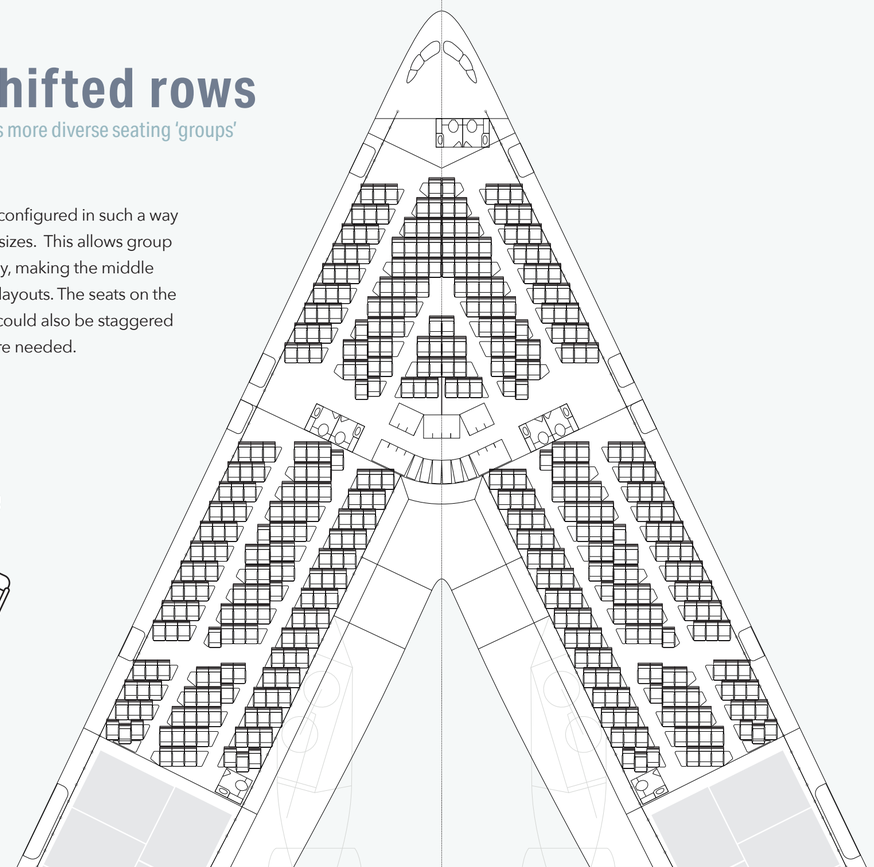
As can be see all concepts currently exceed the typical capacity of between 300 and 350 seats for comparable aircrafts like the Airbus A350. However, the capacities for each of the proposed concepts will likely shrink due to the addition of premium seating, and the addition of more galleys. Notably, the concepts that do contain premium seating already exceed this 300-350 seat margin by 38-88 seats. So, it is expected that during further development the capacities for each concept will not shrink below the typical margins.

shifted rows

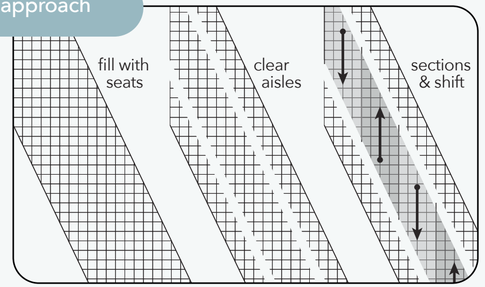
creates more diverse seating 'groups'

The middle rows of the cabin can be configured in such a way to create seating 'groups' of different sizes. This allows group travellers to sit together more privately, making the middle rows more preferable than in current layouts. The seats on the sides are placed in rows of three but could also be staggered to create individual private seats where needed.



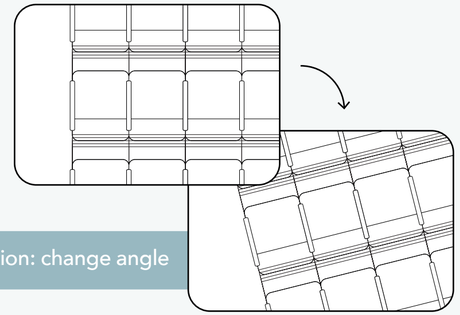


approach

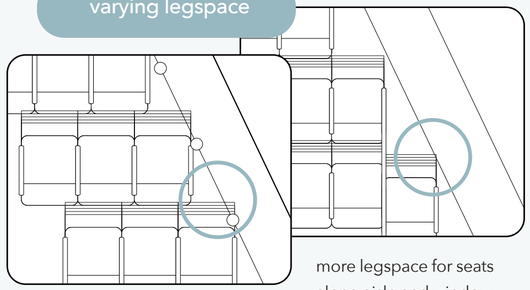


an option worth exploring is changing the initial seating angle, as it likely improves capacity when shifting rows

option: change angle



varying legspace



more legspace for seats along aisle and window

option: group seats

additionally seats can be reversed to create group configurations

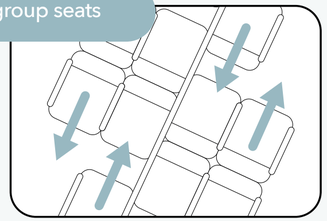
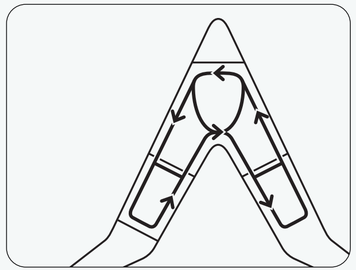


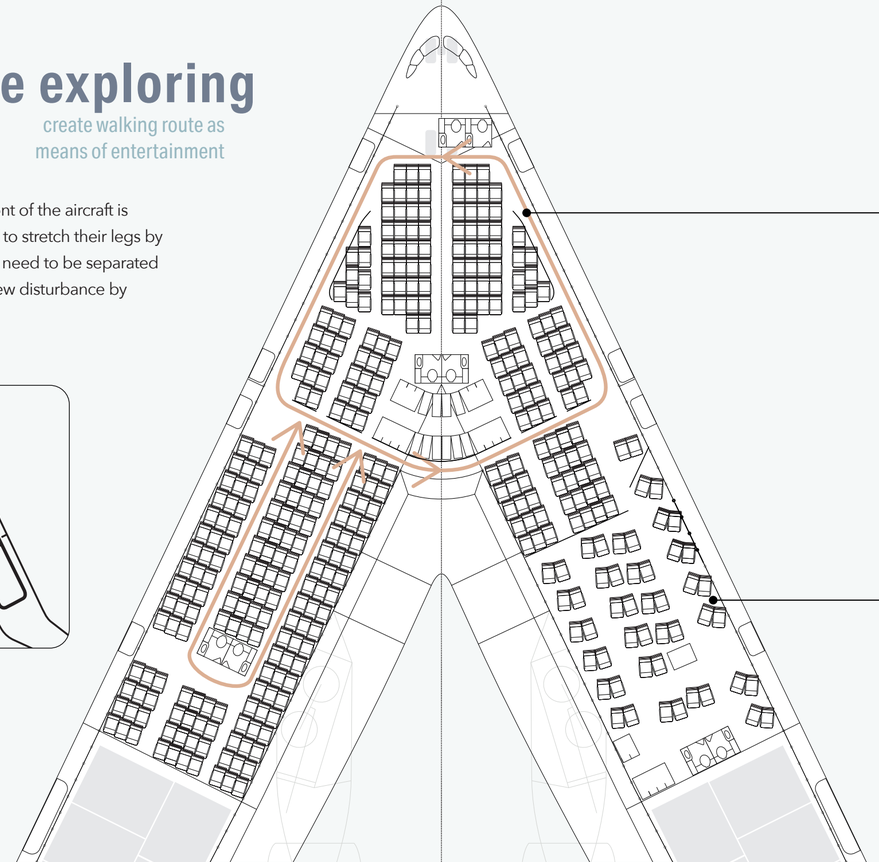
Figure 03-10: design direction 1: shifted rows

promote exploring

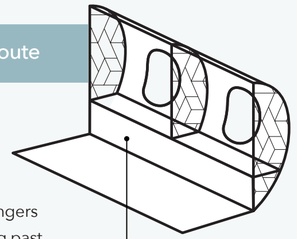
create walking route as
means of entertainment

A walking route around the unique front of the aircraft is created so that passengers are invited to stretch their legs by walking around the plane. The galleys need to be separated from the walking route to minimise crew disturbance by passengers.





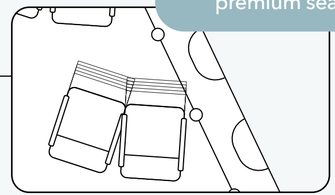
walking route



Walking route is located along the wall with windows so passengers can enjoy the view while walking past.

Secondary seating could be placed between the pillars so passengers can sit down during their walk.

premium seating



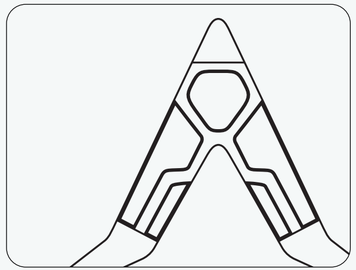
Business class is separated from the walking route and moved to the rear of one of the wings, with premium 'window-facing' seating along the outer wall.

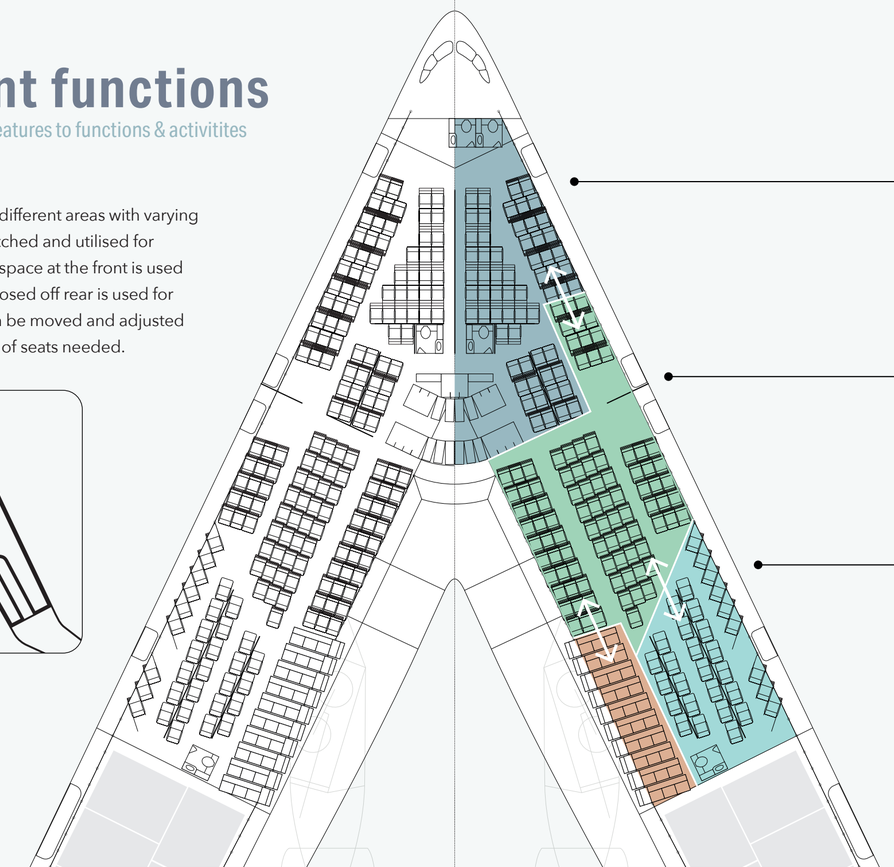
Figure 03-11: design direction 2: promote exploring

different functions

match cabin features to functions & activitites

The Flying-V unique shape creates different areas with varying features. These features can be matched and utilised for different functions. The large open space at the front is used for social seating, while the more closed off rear is used for sleeping and working. Sections can be moved and adjusted slightly, depending on the number of seats needed.

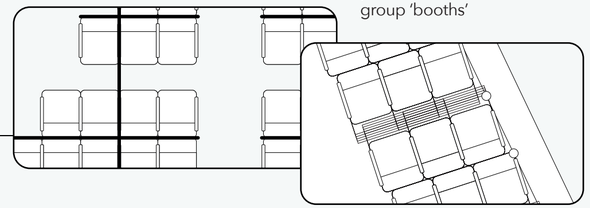




social areas

larger crowded area, used for social group seating

premium closed-off group 'booths'

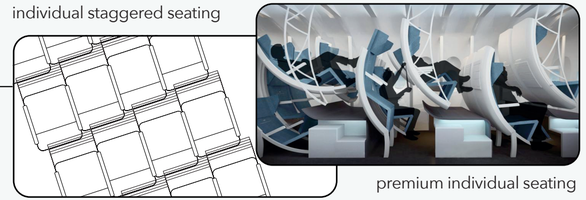


'open' group seating

calm area

more quiet area with individual and small group seating,

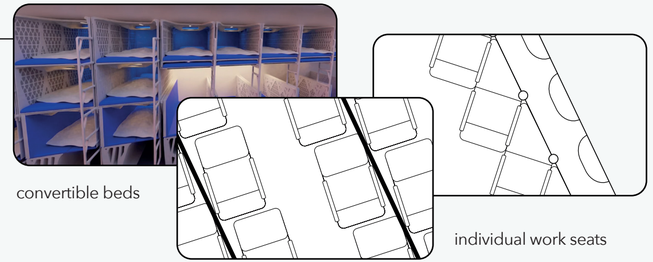
individual staggered seating



premium individual seating

quiet area

quiet area where passengers and crew are less likely to pass by, used for work and sleeping



convertible beds

premium window-facing work booths

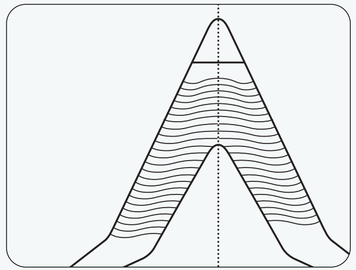
individual work seats

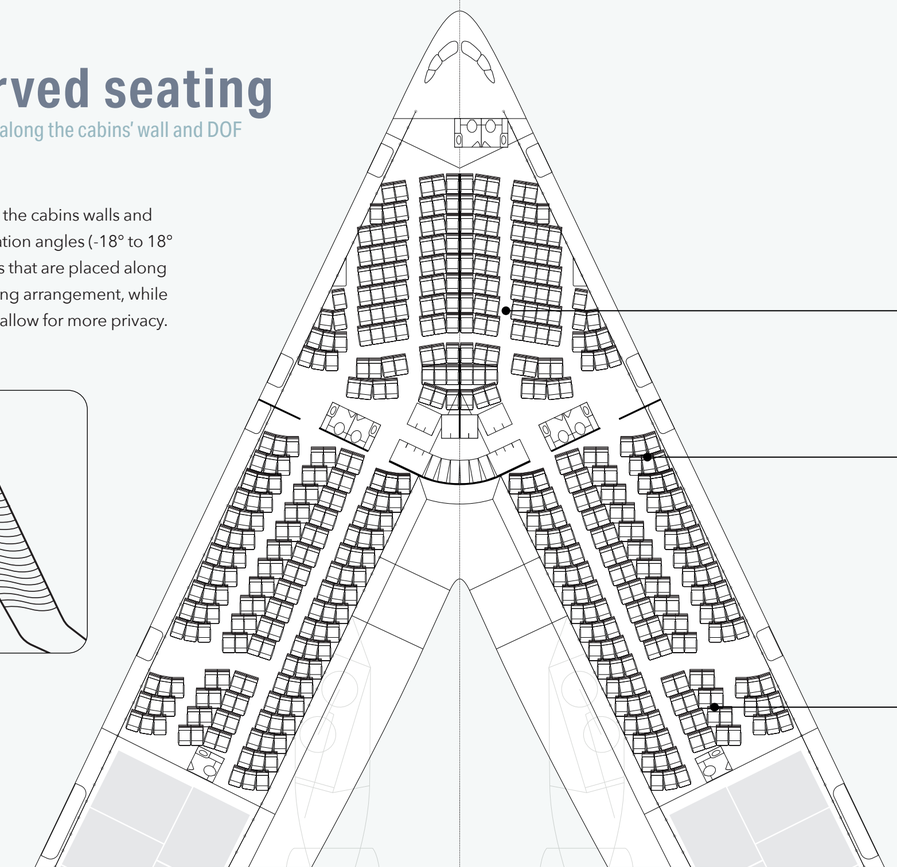
Figure 03-12: design direction 3: different functions

curved seating

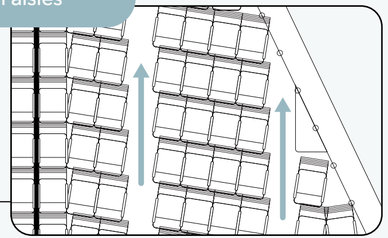
seating curving along the cabins' wall and DOF

Seat orientations are curved along the cabins walls and aisles, utilising the possible orientation angles (-18° to 18° from DOF). The inward facing seats that are placed along the walls create a more social seating arrangement, while seats facing away from each other allow for more privacy.



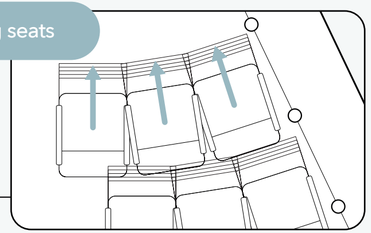


vertical aisles



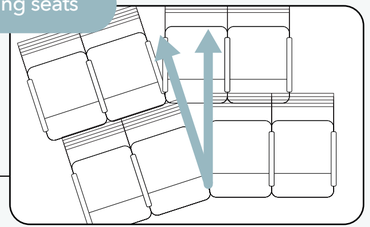
Vertical aisles, limiting the amount of unused space. Rows of three can be served from one aisle, while rows of four can be served from both sides.

inward facing seats



Rows of three seats face each other, making it easier to talk to each other.

outward facing seats



Middle rows contain seats of two facing away from each other. This creates more separation between the seats.

Figure 03-13: design direction 4: curved seating

shifted rows

creates more diverse seating 'groups'

initial layout (29" pitch)

half

row seats:	117
shifted seats:	102
total:	219

total **438**

staggered layout (29" pitch)

half

row seats:	132
shifted seats:	102
total:	234

total **468**

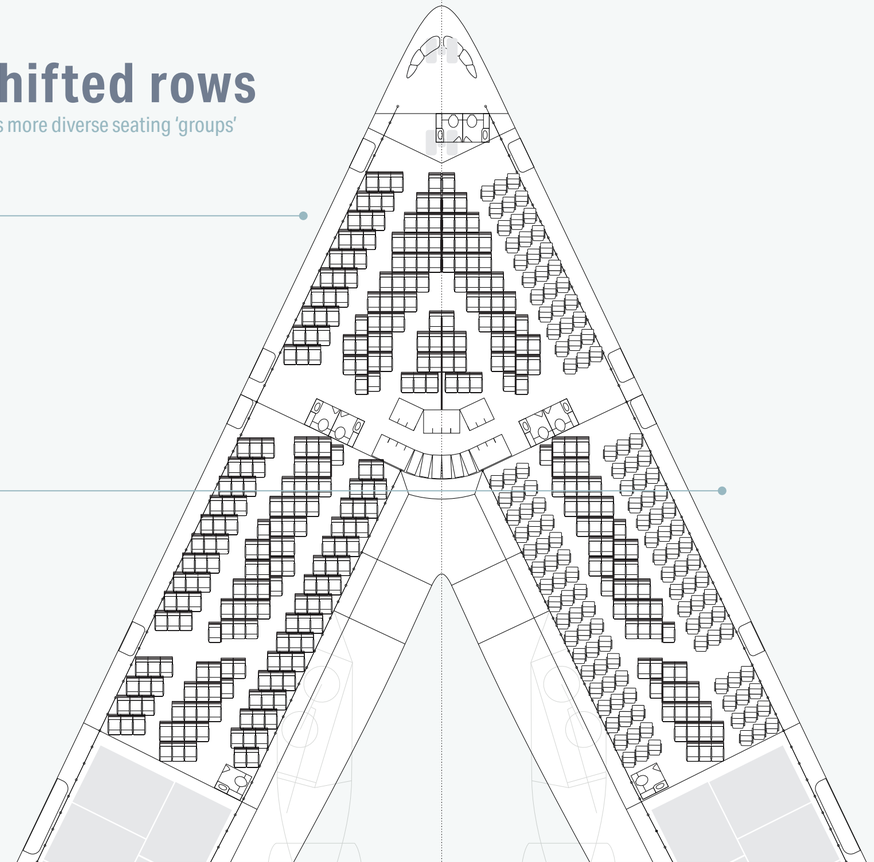


Figure 03-14: capacity direction 1

promote exploring

create walking route as
means of entertainment

without premium seats

half

facing DOF:	41
staggered:	191
total:	232

total **464**

with premium seats (in one wing)

half with premium

row seats:	41
shifted seats:	64
premium:	48
total:	156

total **388**

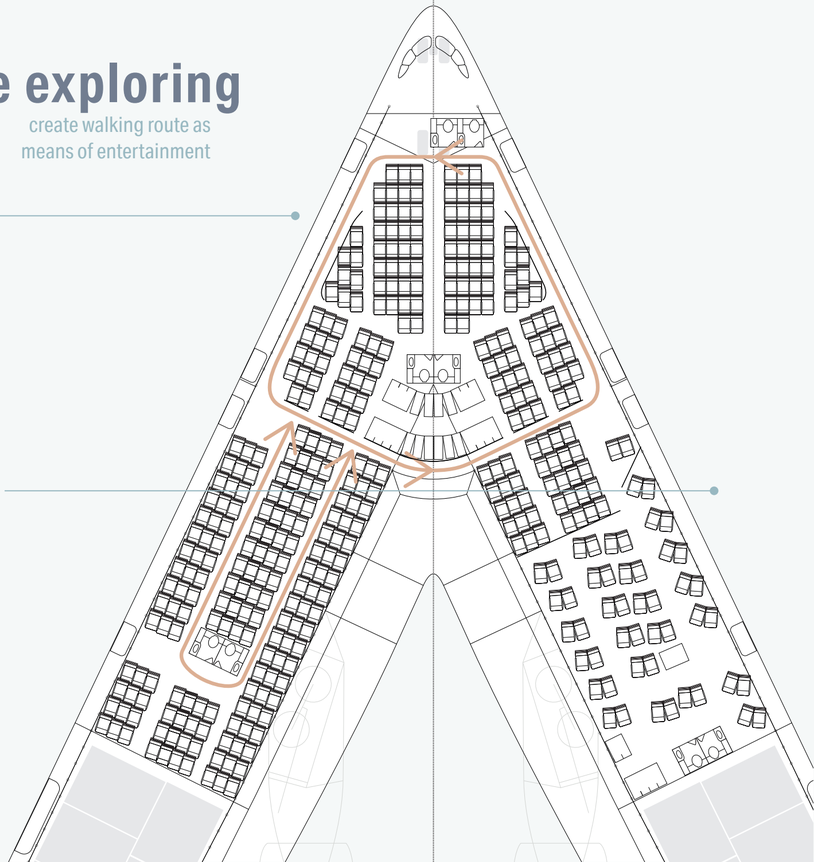


Figure 03-05: capacity direction 2

different functions

match cabin features to functions & activitites

social area

half

open group	49
prem. group	26
total	75

calm area

half

lounge seats	30
staggered	36
rows	15
total	81

quiet area

half

premium work	9
work	23
beds/seats	10 (30)
total:	62

total **436**

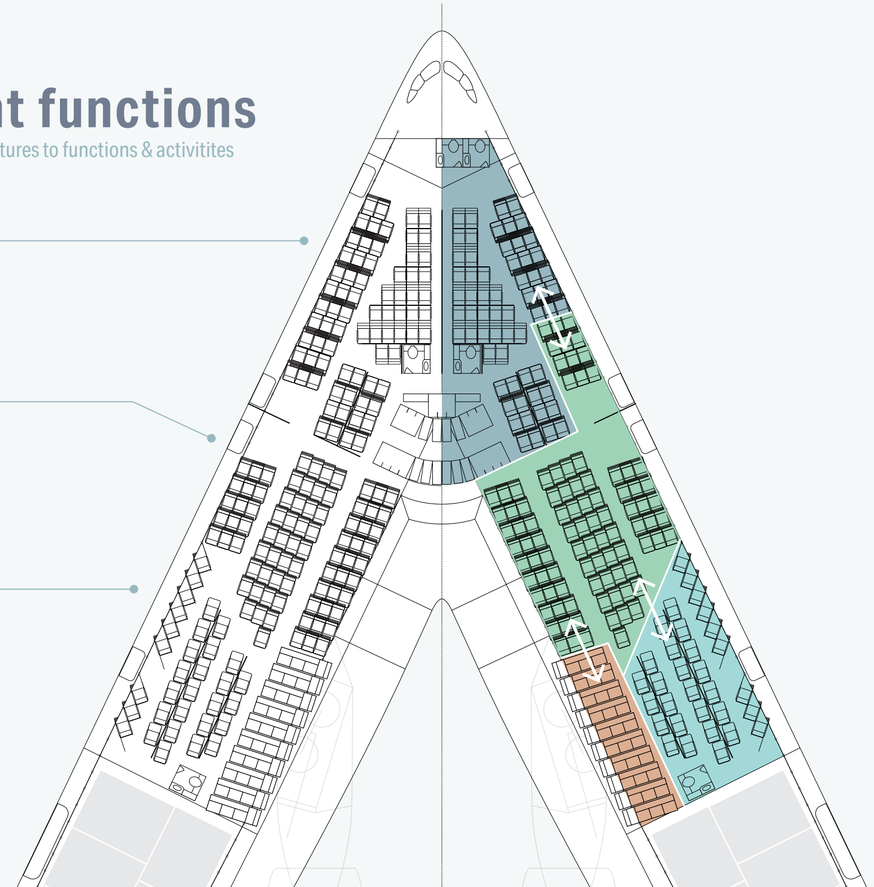


Figure 03-06: capacity direction 3

curved seating

seating curving along the cabins' wall and DOF

without premium seats

half front

facing out	27
straight	29
facing in	23
total	58

half rear

facing out	60
facing in	93
total	153

total **422**

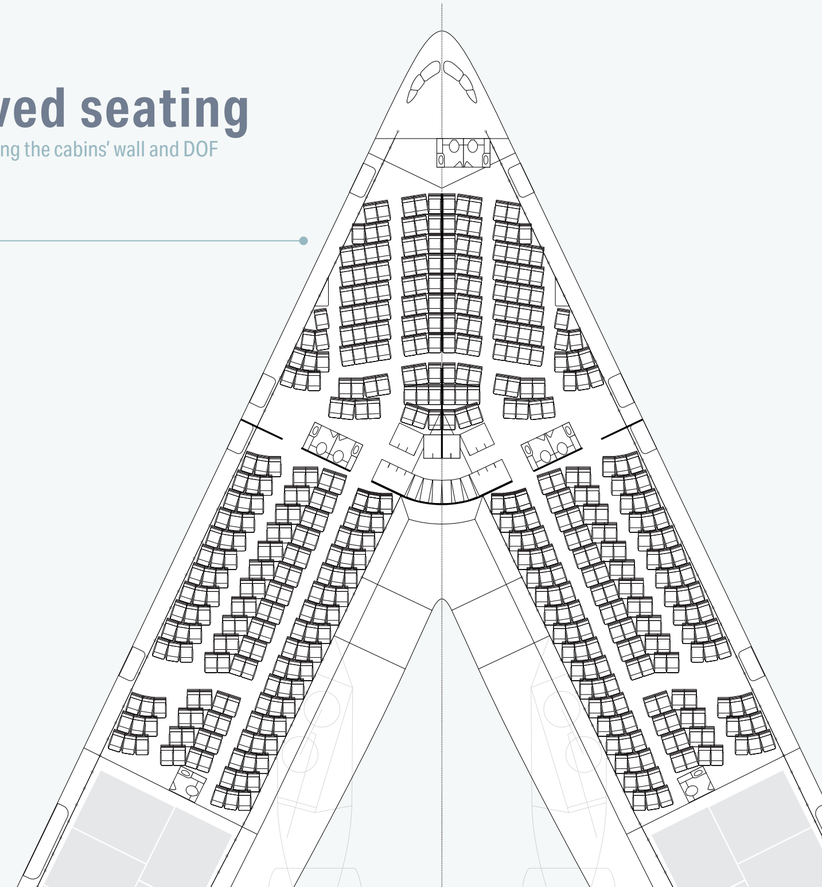


Figure 03-07: capacity direction 4

03
03

direction assessment and choice

01 / approach

In order to choose the most suitable direction, an assessment method was used. This 'traffic light' method uses red, green and yellow markers to assess different aspects of the design or concept. Each colour indicating the following:

- **Red – project killer:** the problem is very difficult to solve.
- **Yellow – needs adjustment:** there is an attainable way to solve the problem.
- **Green – solved:** problem is solved in the proposed design.

For a concept to be valid, all points need to be marked green. This way, for each proposed design direction, a clear overview is created of which criteria need to be prioritised to make the concept work. Additionally, the overview can be used to indicate which directions are closer to being valid, and which need more development.

In this case the assessment criteria contained nine requirements, in addition to seven wishes or goals. The nine requirements were used to filter out which design direction would not work, or which direction would require substantial further development to become valid. The wishes and goals were then used to determine which direction or combination thereof would be most interesting to develop further.

02 / criteria

Based on previous research, several assessment points were defined. These criteria are divided into five categories: improving passenger comfort, crew comfort and concerns, capacity and margin, production and development, and safety and regulations. These assessment points can be found in *figure 03-08* along with a description of each of these points. The criteria under improving passenger comfort and under production and development are considered wishes, the other categories requirements.

improving passenger comfort

Privacy	The floorplan concept improves passenger privacy. Privacy is improved for individual travellers as well as group travellers of different group sizes.
Legroom	Legroom is improved for all seats. Or there is sufficient variety in legroom across seats, allowing passengers to choose seats they prefer.
Sleeping	Comfort of sleeping on the plane is improved compared to regular economy seating, or passengers have sufficient options to choose seats or beds with improved sleeping comfort.
Moving around	The floorplan allows passengers to stretch their legs and move around the plane. The walking route is more entertaining or engaging than in current aircrafts.
Entertainment	Boredom is relieved in some other way than walking around. For example: different food service, additional forms of IFE.)

crew comfort and concerns

Galley access	Crew can easily enter and exit the galleys. Seats are comfortably reachable from the galleys during meal service.
Separation from passengers	Galleys and crew areas are sufficiently separated from the passengers. Preventing passengers from entering the galley or crew area during cruising, especially during meal service.
Food serving	When serving food, crew can access passenger seats from the aisle with less than 2 seat in between. (So rows of 4 seats need galleys on both sides. At maximum, a row of three seats can be accessed from one aisle.)
Crew seating	It is expected that there is enough space for placement of additional crew seating in the galleys or nearby without compromising the required minimum capacity mentioned below.

Figure 03-08: selection criteria for design direction choice

capacity and margins

Minimum capacity	The minimum capacity of 300 (between 300 & 350) seats can be reached with the proposed seating arrangement.
Galley 'margin'	It is expected that there is enough margin in capacity for the proposed seating arrangement to remove seats and make room for additional required galleys or placement of premium seats (e.g. businessclass)
Adaptability	The sections with different type of seating concepts can be adjusted in size to fulfill the varying seating needs across flights while still meeting the minimum recuired capacity mentioned above. (e.g. economy seats can be replaced for economy seats)

production and development

Development	It is expected that the amount of seating and / or interior elements that need to be developed and produced are within reasonable limits to not increase production costs drastically.
Acquisition	It is expected that the majority of interior elements can be acquired from third parties to limit production costs.

safety and regulations

Seating angle	All seating during take-off and landing are within the required limit of 18 degrees from DOF.
Emergency routes	Emergency exist are clear from seats and can be sufficiently accessed, or the proposed concept can be easily adjusted to fit the necessary safety requirements.

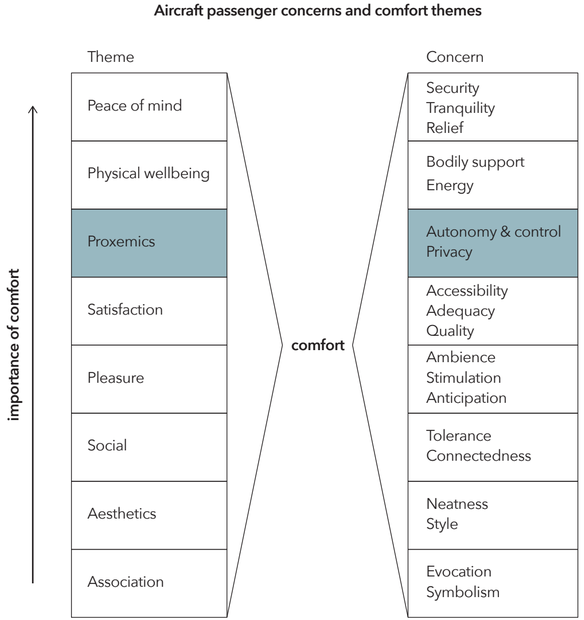


Figure 03-09: aircraft passenger concerns and comfort themes (Ahmadpour, 2014)

Improving Passenger comfort

Several aspects were defined that should be tackled to improve passenger comfort during cruising: privacy, legroom. moving around, sleeping and additional forms of entertainment. Noteworthy is that the assessment criteria under this category don't all have to be met, since they are mere suggestions of which aspects can be tackled to improve passenger comfort. However, some of these criteria will be more effective in improving overall passenger comfort during cruising than others.

Research by Ahmadpour et al. (2014) showed several comfort themes and passenger concerns and placed them in order of importance for comfort *(figure 03-09)*. This indicated that the perception of privacy, regarded under the theme proxemics, is considered highly important for improving passenger comfort. Additionally, research by Vink et al. (2012), defined the correlation between different flight aspects and comfort, in addition to comfort scores for each of these aspects. This indicated a low comfort score for personal space *(figure 03-10)*. Together, this suggest that improving personal space and privacy will largely affect overall passenger comfort during cruising. The need for improved privacy is also indicated in passenger experience research in this report (*chapter 2.3.3, p. 62*). Here respondents mentioned experiencing negative emotions when passengers disturbed them or invaded their personal space unannounced.

Furthermore, the latter mentioned research by Vink et al. (2012) indicated a high correlation between legroom and comfort (0.72), but a low comfort score for this aspect *(figure 03-10)*. Meaning that legroom is also one of the aspects that needs to be prioritised when aiming to improve overall passenger comfort. ▸

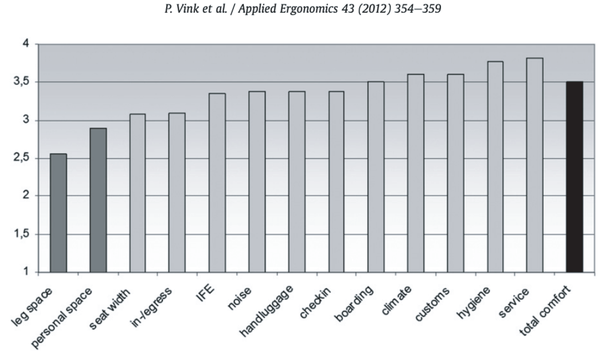


Figure 03-10: comfort scores for various comfort aspects (Vink, 2012)

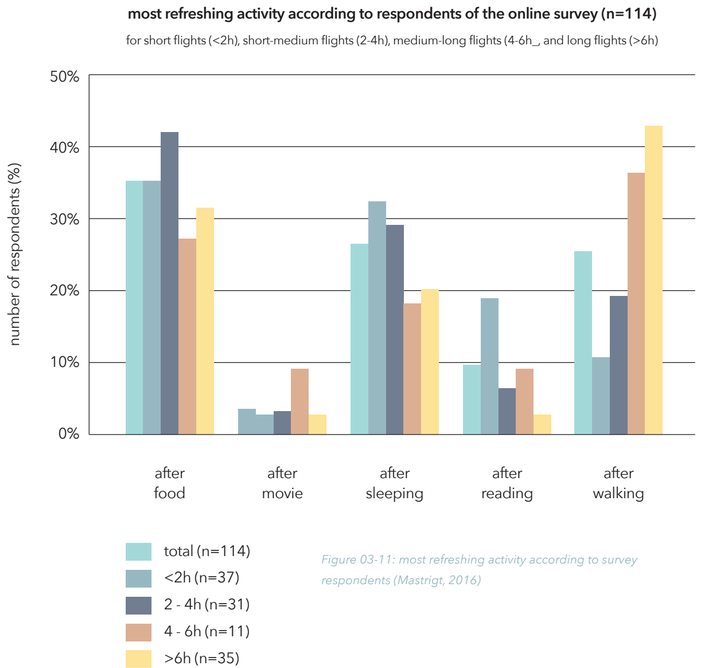


Figure 03-11: most refreshing activity according to survey respondents (Mastrigt, 2016)

Furthermore, research by Mastrigt et al. (2016) defined which activities were most refreshing for passengers on flights with different durations *(figure 03-11)*. It indicates that on long-haul flights (>6 hours) and on long-medium haul flights (4-6 hours), walking around will make passengers feel most refreshed. This means that improving the possibilities of moving around the plane will likely improve passenger comfort. This aspect was also mentioned in research in *chapter 2.3.3*, where respondents mentioned the desire for more interesting walking routes around the plane.

Collectively, these conclusions indicate that the criteria privacy, legroom, and moving around should be prioritised during assessment and direction choice.

03 / assessment

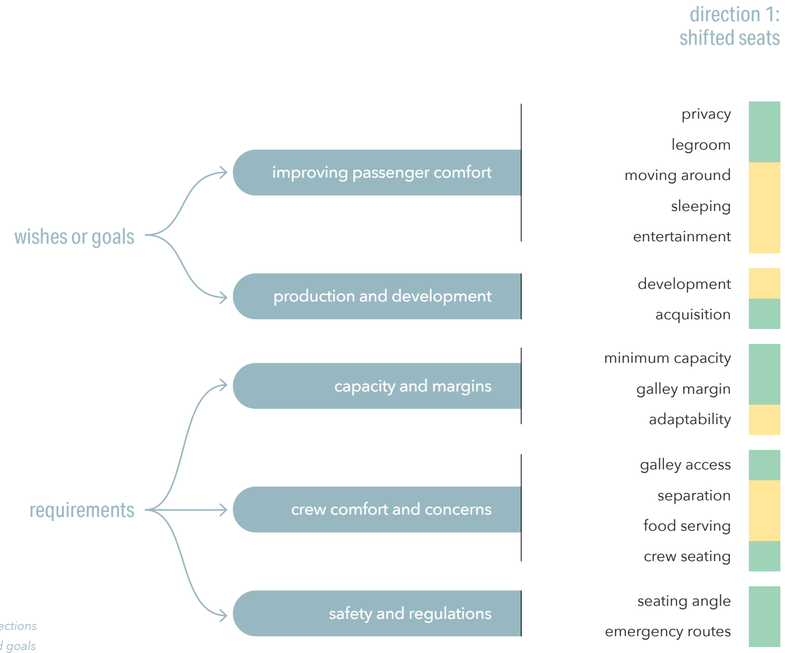
Each of the directions were assessed on the 16 assessment criteria described previously. The assessment sheets for each direction can be found in *appendix D*. Those assessment sheets further elaborate on why each of the marks were applied, and how each of the problems indicated by a yellow mark could potentially be solved. A simplified overview of the assessment can be seen in *figure 03-12*.

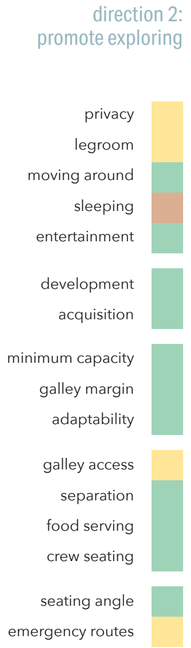
04 / conclusion & direction choice

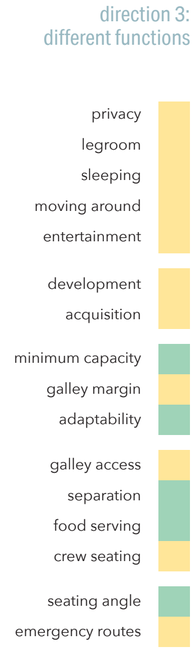
As can be seen all design directions only have green or yellow markers in the requirements section. This indicates that when looking at these requirements, all directions could be used for further development. However, out of the four directions, direction 3 has substantially more yellow markers than the other concepts (four for the requirements, compared to three for direction 1 and 4, and two for direction 2). Additionally, the concept has many yellow markers in the wishes section. This indicates that this design direction would require substantially more development than the others. With regards to further development in this project and considering the timeline, it is therefore wiser to choose one of the other three remaining directions for further development.

Noteworthy here is that directions 1 and 4, both aim to improve the passenger comforts ‘privacy’ and ‘legroom’ in different ways. Direction 2 on the other hand, mainly focusses on improving different discomforts, namely ‘moving around’ and ‘additional entertainment’. By integrating different seating configurations, (possibly directly taken from directions 1 and 4), the comfort aspects ‘privacy’ and ‘legroom’ can be improved in this design direction as well. Additionally, design direction 2’s walking route exploits the unique layout of the aircraft to its advantage, possibly giving the the aircraft a marketing advantage that is difficult to copy on other aircrafts.

Therefore, the design direction used for further development will incorporate a walking route and secondary seating from direction 2, combined with seating configurations similar to those in direction 1 and 4.







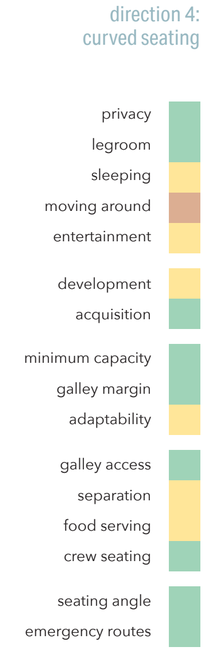


Figure 03-12: assessment of design directions based on requirements, and wishes and goals

03
04

problem definition
design goal

01 / design goal

The defining of the design goal was based on findings in the research phase and assessment of different design directions. The overlapping goal of each of the design directions was to improve passenger comfort during cruising, with each direction solving this in different ways.

Research in the initial phase and during direction selection indicated that improving sense of privacy and legroom, and improving the experience and possibilities of stretching and walking around the plane will effectively improve overall comfort during cruising. Consequently, improving these three aspects will be the main focus of the design goal used for further development.

> *"Design a floorplan for the Flying-V with the aim of increasing overall passenger comfort during cruising through improvements in sense of privacy and legroom, and the possibilities and the experience of walking around. The seating configurations that improve these three aspects should be optimised for different types of travel groups (single, couple, group and premium travellers)."*

Research in *chapter 2.3.2 (p.60)* also showed that different travel group sizes have different seat preferences. This seat preference is likely influenced by these three aspects as well. Therefore, these three factors need to be filled in differently for different group sizes. The privacy aspect especially requires different seating configurations, since groups prefer sitting together, and individual travellers want individual privacy. These considerations resulted in the formulation of the following design goal. ▸

Furthermore, a list of requirements and wishes was created for the development of the proposed concept *(figure 03-13)*. The list also contains references to chapters that introduced these guidelines. Noteworthy is that some of these guidelines stem from additional research done as described in the following chapter.

wishes

Passenger capacity & distribution	The floorplan allows for around 350 passengers	2.1.2
	The distribution of seating types should approach the distribution of travel group sizes. I.e. 45% individual seats, 35% couple seats, 20% group seats.	4.1.1
	The different types of seating should still be useable for other types of travel groups than intended without largely compromising passenger comfort.	4.2.4
Galley & lavatory capacity & distribution	Galleys should ideally be placed together.	2.4.1
	Lavatories should ideally be placed together.	2.4.1
	Ideally, galleys and lavatories should be placed separate from each other to prevent passenger-crew interference.	2.4.1
	Lavatories should be placed along the main walking route	
	If a self-service food concept is included, this should be placed along the main walking route	
Passenger comfort	Measures are taken to further improve passenger comfort in relation to legspace and privacy, by for example: · using seats designed with a thinner-backrest · placing (moveable) partition walls between seats · angling seats away from each other · angling seats so that the empty space between · space between the pillars and walls can be utilited as extra legspace	3.3

E.g. when individual passenger are placed in group seats, their privacy should not be decreased compared to conventional seating.

Figure 03-13: requirements and wishes for the proposed floorplan design

constraints

Passenger capacity & distribution	The floorplan should allow for at least 300 passengers. This includes both economy and premium passengers	2.1.2
	At least 13% of all seating should be premium class (first and business or combined)	4.1.2
Galley & lavatory capacity & distribution	The floorplan should allow for sufficient space for the amount of galley carts and/or additional self service concepts needed defined by the number passengers on board.	4.3.1 4.3.2
	The floorplan should allow for at least 8 lavatories with a passenger capacity between 300 and 350. Or a minimum of 6 if other lavatory concepts such as a refleshment area are included.	4.3.3
Passenger comfort	Passenger comfort in relation to legspace and privacy should be increased compared to average economy seating. · A minimum seat pitch of 31", or a pitch with similar comfort scores for staggered seating. · At least one design measure should be taken to improve privacy for individual, couple and group travellers.	4.2
Seating configurations	Passenger seats that are used during take-off and landing should not be angled more than 18° from DOF.	2.1.2
	There should be no less than 2 passenger seats in-between a passenger seat and an aisle.	
Crew comfort & concerns	Galley areas should not be placed along the main walking route for passengers	3.2.1.2 3.3.3
	There should be a minimum of 8 crew seats included in the floorplan	2.1.2
	There should be a dedicated resting area for crew in the main cabin or front of cargo area	2.1.2
Aisle width	The main walking route should have minimum aisle width of 1m.	4.4.1
	Aisle width should not be smaller than 381mm below 640mm height, and 508mm above 640mm height.	2.4.2.3
Emergency exits & routes	Emergency exists should be directly accessible from the neighbouring aisle, without seats or other interior elements obstructing the path.	

Calculations are done with a cart capacity of 30 meals, and serving 3 meals per passenger. This includes a cart capacity margin for carts used for serving foods and drinks.

If self service concepts are included, the cart capacity can be increased to a maximum of 42 meals per cart.

Secondary seating that is only temporarily used can exceed this maximum angle.

For ease of food service and passenger ingress and egress

These areas should be separated to prevent passenger-crew interference.

04 00

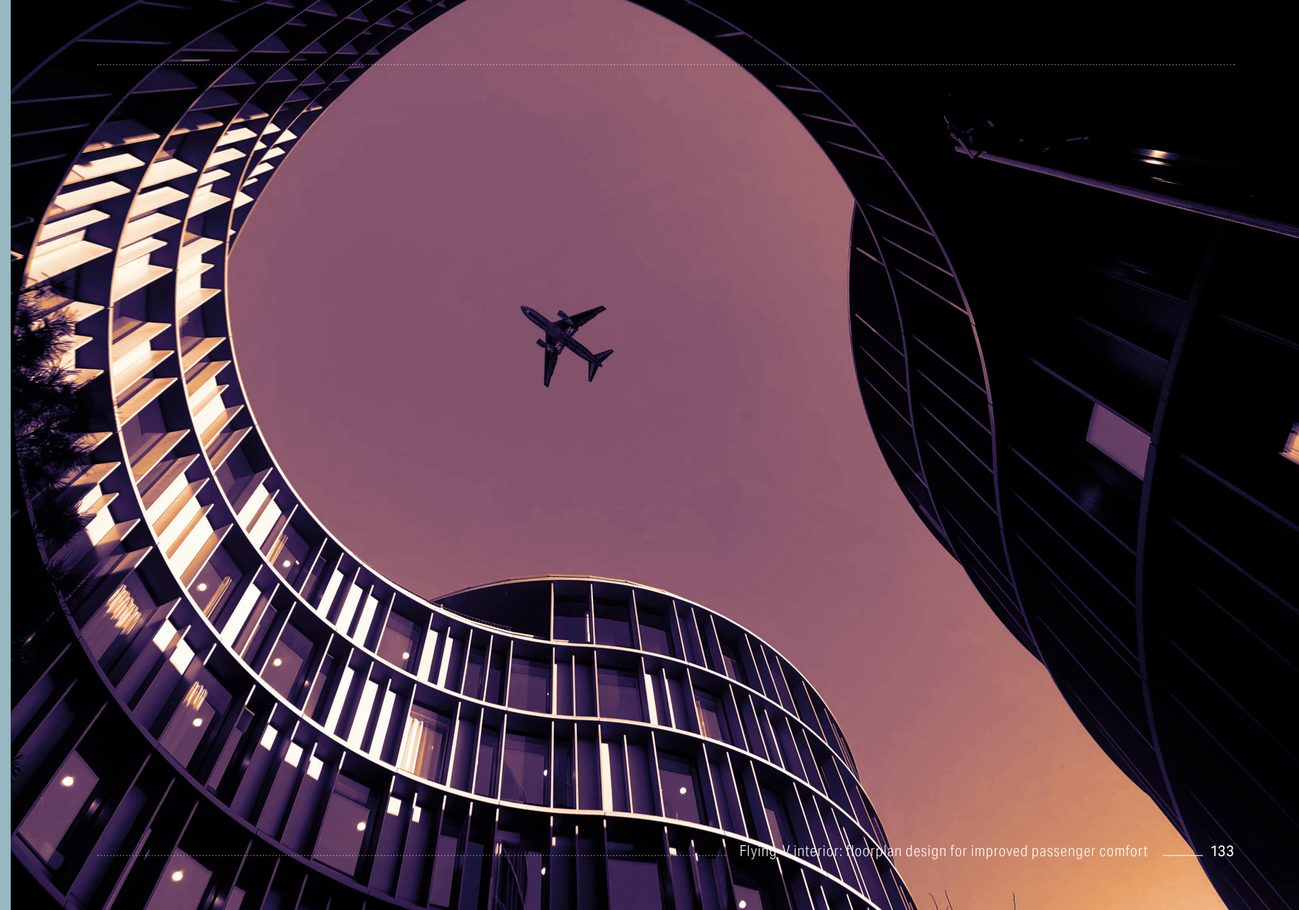
concept development
defining the floorplan

/ 01 types of passenger groups and preferred seating

/ 02 seat staggering: compromising between capacity, legroom and privacy

/ 03 galleys & lavatories: capacity, dimensions, and placement

/ 04 additional interior elements



04 01

types of passenger groups and preferred seating

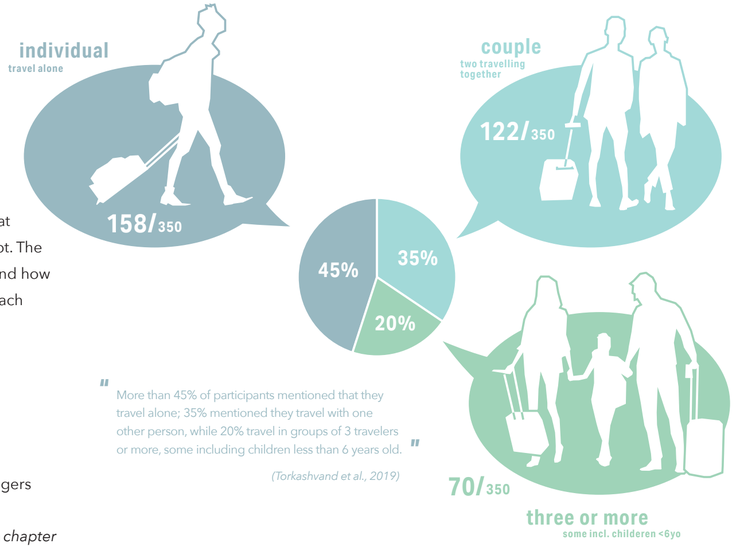
// 01 distribution of passenger group sizes

// 02 premium class share

The distribution of different travel group sizes and premium passengers directly influences the distribution of the different seating configurations that need to be incorporated in the final floorplan concept. The following chapter indicates what this distribution is and how this correlates to the amount of seats necessary for each travel group.

01 / distribution of passenger group sizes

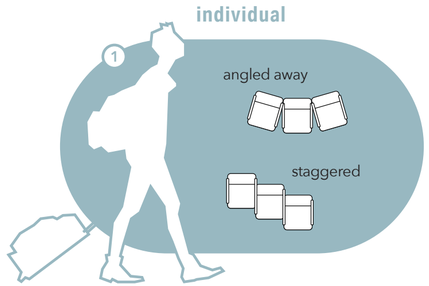
Research by Torkashvand (2019) showed that passengers travelling in different group sizes have different seat preferences. This research is further elaborated on in *chapter 2.3.2*. Ultimately, these passengers want to sit within their travel group, with seats on the window side being generally preferred. Additionally, this research defined the distribution of travel group sizes as shown in *figure 04-01*. ▸

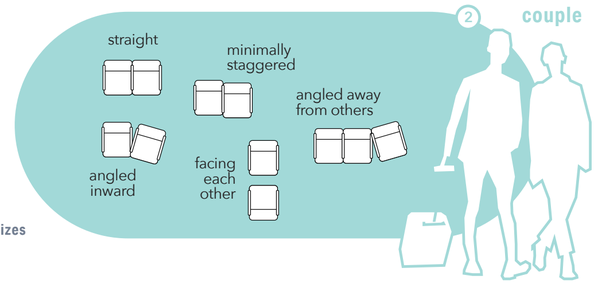


> More than 45% of participants mentioned that they travel alone; 35% mentioned they travel with one other person, while 20% travel in groups of 3 travelers or more, some including children less than 6 years old.
>
> *(Torkashvand et al., 2019)*

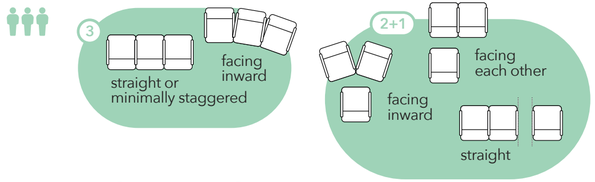
Figure 04-01: types of travel group sizes and distribution thereof (Torkashvand, 2019)

Important about this is that the passenger comfort "privacy" can be defined differently for individual travellers and group travellers. Individual travellers prefer sitting alone, while group travellers want privacy within their travel group, separating their travel group from others.
This means that optimal seating configurations with relation to privacy vary among travel group sizes. *Figure 04-02* illustrates which seating configurations, resulting from design directions presented in *chapter 3*, are appropriate for different group sizes with regard to improving privacy.

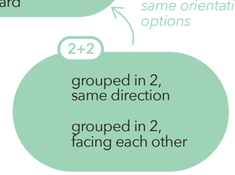




suitable seating configurations
for different travel group sizes



same orientation options



three or more
some incl. childeren <6yo

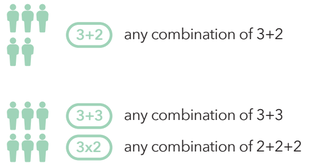


Figure 04-02: suitable seating for different travel groups

02 / premium class share

In addition to travel group sizes, the share of premium seating in the aircraft needs to be incorporated into the final floorplan. A report by IATA and DIIO in 2017 (IATA, 2017) states that:

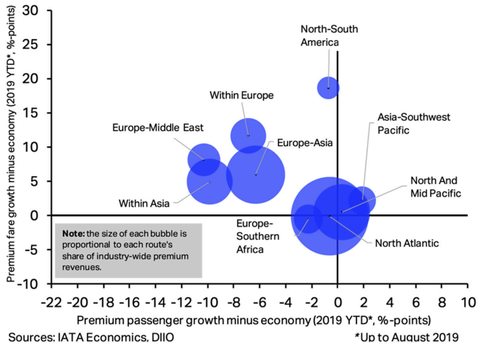


Figure 04-03: premium class growth and distributions (IATA, 2019)

"at the industry-wide level premium-class travellers (ie, combined first and business class) accounted for a modest 5.2% of total international O-D passengers … the premium cabin's share of total passengers ranges from around 5% on international routes within Asia to nearly 13% across the North Atlantic." Accompanied by the following graphic, illustrating the distribution *(figure 04-03)*.

Reports from 2019 (IATA, 2019) show slightly decreased percentages, while also illustrating that premium passenger share is shrinking..

"Premium-class passengers accounted for 5.0% of total international origin-destination traffic in the first eight months of 2019. This proportion was marginally lower (down 0.1ppt) compared to the same period a year ago."

When looking at existing floorplans for the flying-V, a high share of premium seats can be seen. The initial floorplan that was developed contained 314 seats, of which 15.3% (48 seats) reserved for first and business class. The later developed floorplan, which incorporated slightly staggered seating, contained 340 seats of which 14,7% premium (50 seats).

Likely, this share is on the higher side to ensure there is enough accommodation for premium passenger when needed. Premium passengers are prioritised because they account for a large percentage of the total revenue of a flight *(figure 04-04)*. (Around 47% over the Atlantic, IATA 2017)

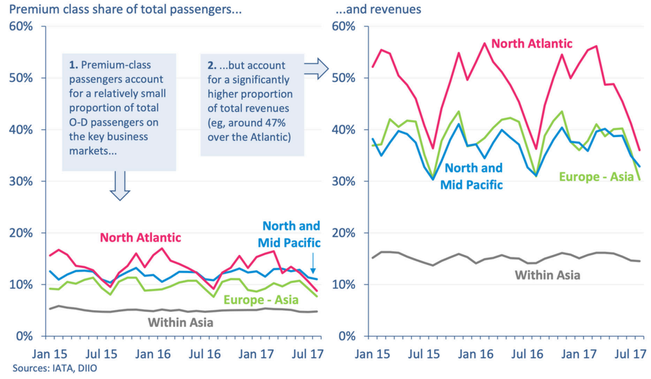


Figure 04-04: premium passenger share and revenues

Even though the average share of premium passengers is around 5%, percentages on the higher end of the spectrum (13-15%) are used for further development. This is done to ensure there is always enough capacity for premium passengers when needed.

Additionally, by placing premium passengers in a section of one of the wings instead of at the front, more opportunity for variation across planes is created as the separation wall between these passenger groups can more easily be shifted than if they were positioned at the front of the aircraft.

04 02

seat staggering: compromising between capacity legroom, and privacy

// 01 possible effect of row width on capacity

// 02 seating angle: effect on increase in legroom and row width

// 03 staggering step: effect on privacy and row width

// 04 proposed layout

In order to comply with FAA regulations all seats will have to be angled slightly in relation to the cabin wall. One option is to stagger the seats so they are not directly placed next to each other. The dimension with which these seats are staggered have an influence on passenger privacy, effective increase in legroom and row width. Row width indirectly has an effect on capacity, because it affects whether a 9 or 10-abreast configuration is possible.

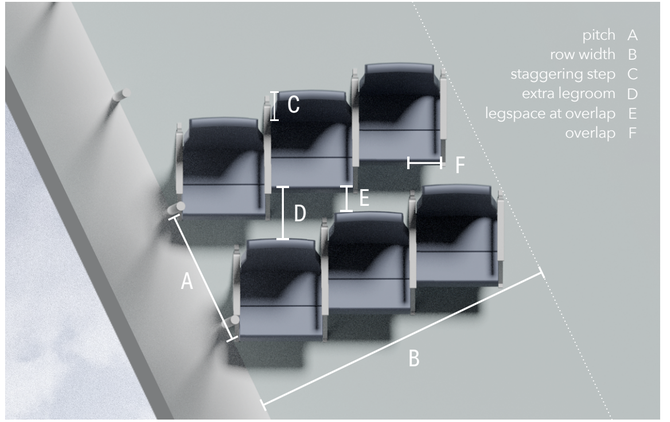


Figure 04-05: staggered seat dimensions

dimensions influencing passenger comfort and capacity

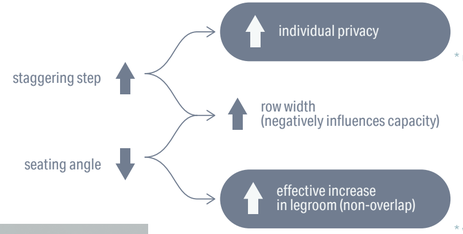


Figure 04-06: effect of staggering step and seating angle on privacy, row width and effective increase in legroom

Figure 04-05 gives an overview of the different dimensions taken into account, and *figure 04-06* summarises how the the comfort aspects privacy and legroom are affected. The following chapter will elaborate on this more.

01 / possible effect of row width on capacity (in a staggered configuration)

When seats are placed in rows perpendicular to the cabin wall (25.5°), changing the seating angle will, among other dimensions, influence row width. Indirectly, this affects capacity as it determines whether a 9- or 10-abreast configuration is possible within the cabins dimensions and minimum aisle width. *Figure 04-07* shows the effect of different seating angles (0°, 5°, 10° and 18° from DOF) on capacity. All with a 29" pitch and not taking into consideration the space need around emergency exits.

As can be seen, seating angles between 0° and 10° from DOF will only allow for a 9-abreast configuration with 180 passengers. Increasing the pitch slightly above 10° will allow for a 10-abreast configuration, which will increase passenger capacity in one wing by 20 (40 in total).

However, decreasing row width by increasing seating angle will come at the expense of improvements in privacy and legroom, as it also affect other seating dimensions. The question arises which seating angles and other dimensions are still acceptable to effectively increase passenger comfort with regard to these factors.

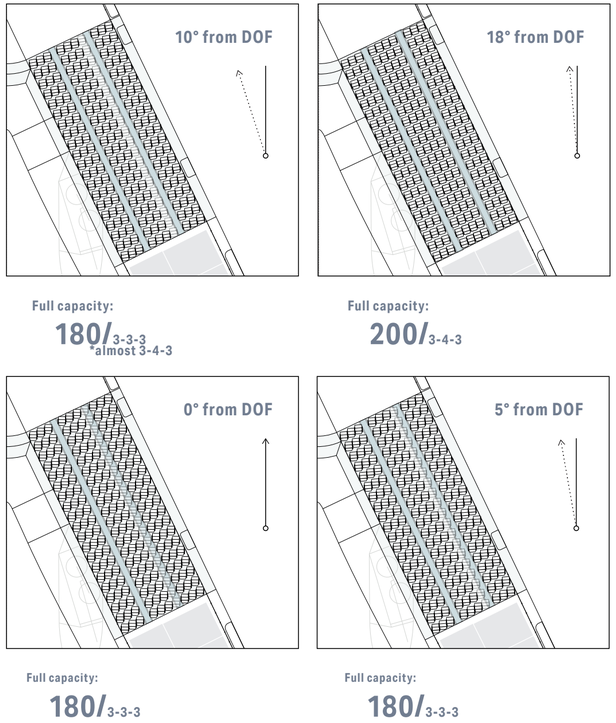


Figure 04-07: seating angle and effect of row width on capacity

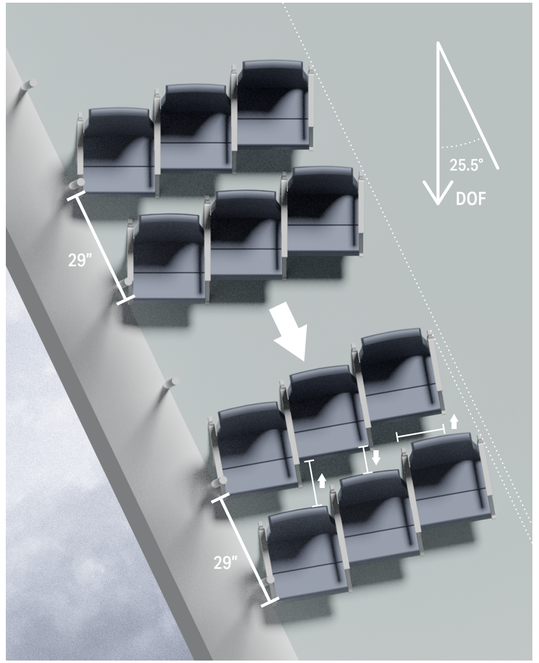


Figure 04-08: effect of increasing the seating angle

02 / seating angle: effect on increase in legroom and row width

When the seating angle is increased, and the pitch between seats and the staggering step are kept the same, several dimensions will be affected. As can be seen in *figure 04-08*, legroom will be increased for one part of the seat *(extra legroom, figure 04-05)* and decreased at another part *(legroom at overlap, figure 04-05*.

increasing seating angle
(from DOF)

same:
· staggering step
· 29" pitch

concequences:
+ more extra legroom
– less legroom at overlap
+ decreased row width
– more seat overlap

Important here is that increasing seating angle increases seat overlap, which is the dimension where legroom is also decreased. *Figure 04-09* gives an overview of the amount of seat overlap for seating angles between 0° and 18° from DOF.

This means that at a certain point the seating overlap becomes so large that the extra legroom cannot be used effectively anymore. This can be seen in *figure 04-09,* where at around 10° more than half of the seat overlaps with the seat in front.

Especially at 18°, where overlap is around 82%, increasing overall pitch will likely be more effective in increasing perceived legroom since the configuration approaches that of conventional non-staggered seating.

One effect of staggered seating worth mentioning is the issue of interference between passenger seating space and aisle space. When seats are staggered at small angles (e.g. 0° from DOF), passengers in seats facing the aisle are likely to place their legs in this aisle. This could possibly prevent crew from comfortably moving along the aisle with airline carts. When the seating angle increases, this problem occurs less. Additionally, with seats staggered along the window side of the aisle, this problem does not occur.

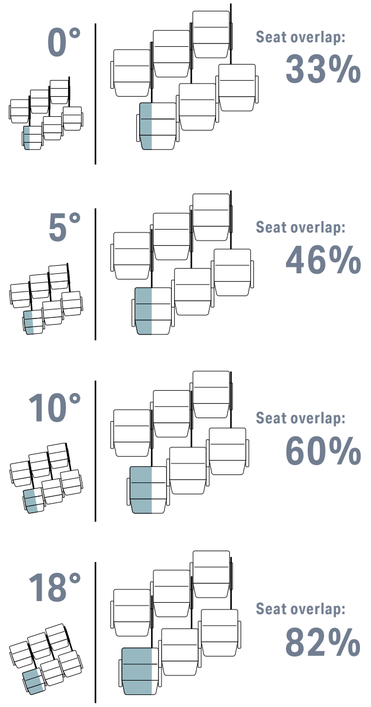


Figure 04-09: seat overlap at different seating angles (0, 5, 10, and 18 degrees)

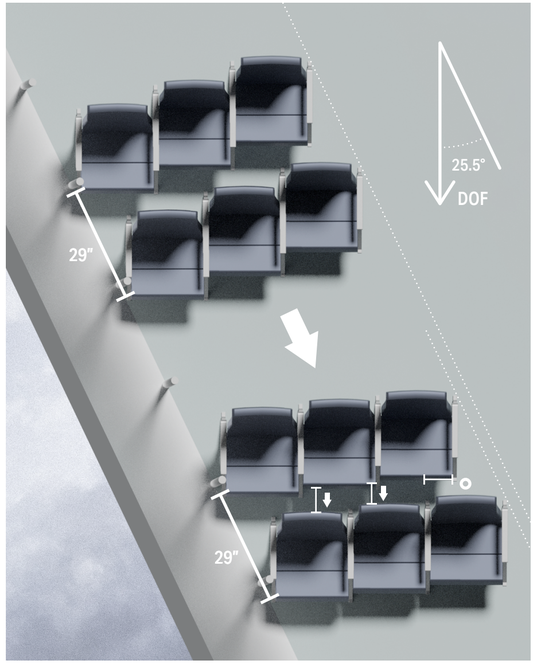


Figure 04-10: effect of decreasing staggering step

03 / staggering step: effect on privacy and row width

In order to improve privacy, the staggering step between seats needs to be large enough. *Figure 09-10* shows that decreasing the staggering step will place seats more alongside each other, decreasing perception of privacy.

decreasing staggering step

same:
seating angle
29″ pitch

concequences:
– less extra legroom
– less legroom at overlap
+ decreased row width

Furthermore, this figure shows that decreasing the staggering step also negatively influences legroom. One positive effect is that decreasing staggering stap might in some cases have a positive effect on capacity as row width is decreased as well.

Worth mentioning is that with a small staggering step and small seating angle, rows will not be perpendicular to cabin walls anymore. This might cause some space to be lost at the front and rear of the cabin *(figure 04-11)*. Here, using a configuration with a larger seating angle and small staggering step that is perpendicular to the cabin wall will be more effective with regard to capacity.

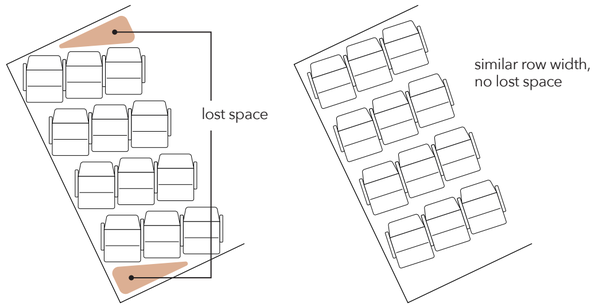


Figure 04-11: how perpendicular rows create more efficient empty spaces

04 / proposed layout

In order to find a suiting balance between privacy, legroom and capacity, differences between passenger needs need to be taken into consideration as well.

Increasing privacy means something different for individual travellers and group travellers. Individual travellers want to be individually separated from other travellers, while couple and group travellers want privacy within their own group. This means that staggered seating is much more suitable for individual travellers than group travellers. And minimally staggered seating, which is similar to conventional configurations, is more suitable for couple and group travellers because it more easily allows passengers to socialise with each other.

A floorplan was developed with different seating configuration for these different travel groups. This preliminary floorplan can be seen in *figure 04-12*. Suitable seating for these different groups was taken into consideration as well as the distribution of these travel groups as described in *chapter 4.1.1 (p. 135)*

As can be seen the size of the sections with different seating types approached the distribution of travel group sizes. Worth mentioning is that when these sizes of these groups differ during a flight, for example if there are more individual travellers, these passengers can still easily be placed in seats dedicated to group or couple travellers. This would for example be more difficult if the group seats were designed to face each other, as it would negatively affects the privacy of the individual passenger. A similar issue is mentioned in research exploring existing concepts for the Flying-V. (Vink, 2020). Here, airline planners mentioned it might not be conventient to turn 28% of seats into group spaces where passengers sit facing each other, as it will likely result in unbooked seats if only a smaller percentage of passengers travel in groups.

Additionally, all seating types show similar comfort scores. Research by Liu et al. (2021) indicate of comfort score of 6.7 for seats staggered at 26°, with 29″ pitch and 17″ seat width. It also mentions the same comfort score of 6.7 for conventional seating with a pitch of 32″ and 17″ seat width. Additionally, research by Anjani et. al. (2020) mentioned that a comfort score of 6.7 is considered high for contemporary economy class seating.

Even though in this proposed floorplan the group and couple seats are placed at 31″, this pitch will be increased to 32″ at the expense of some capacity, in later floorplans described in this report. This is done to ensure equal comfort scores for all travellers.

Furthermore, this proposed floorplan only contains the conceptual placement of galleys and lavatories *(figure 04-12, left image, orange sections)*. The exact placement and capacities hereof will be further elaborated on in following chapters.

travel group sizes & suitable seating

individual seats

98 = **45%**

staggered at 25.5° ·
0° DOF seating angle ·
29″ pitch (6.7 comfort score) ·

couple seats

51 = **31%**

minimally staggered ·
18° DOF seating angle ·
31″ pitch (32″ = 6.7 comfort score) ·
partition walls to improve privacy ·

group seats

68 = **23%**

minimally staggered ·
18° DOF seating angle ·
31″ pitch (32″ = 6.7 comfort score) ·
rows of three ·

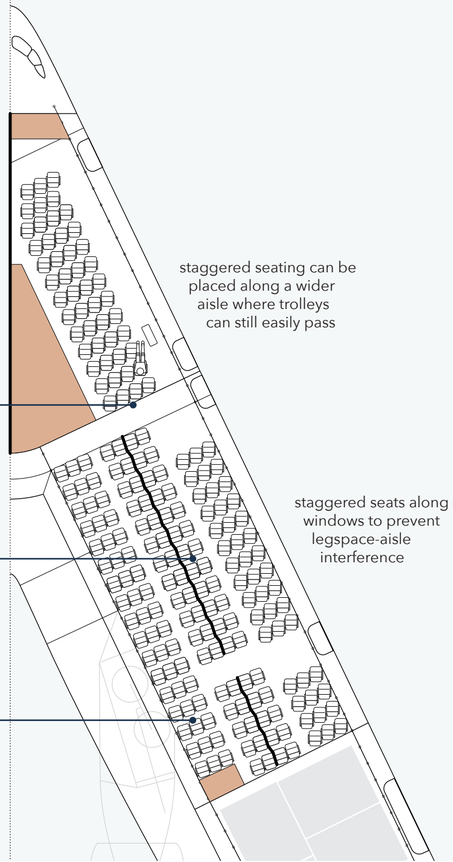
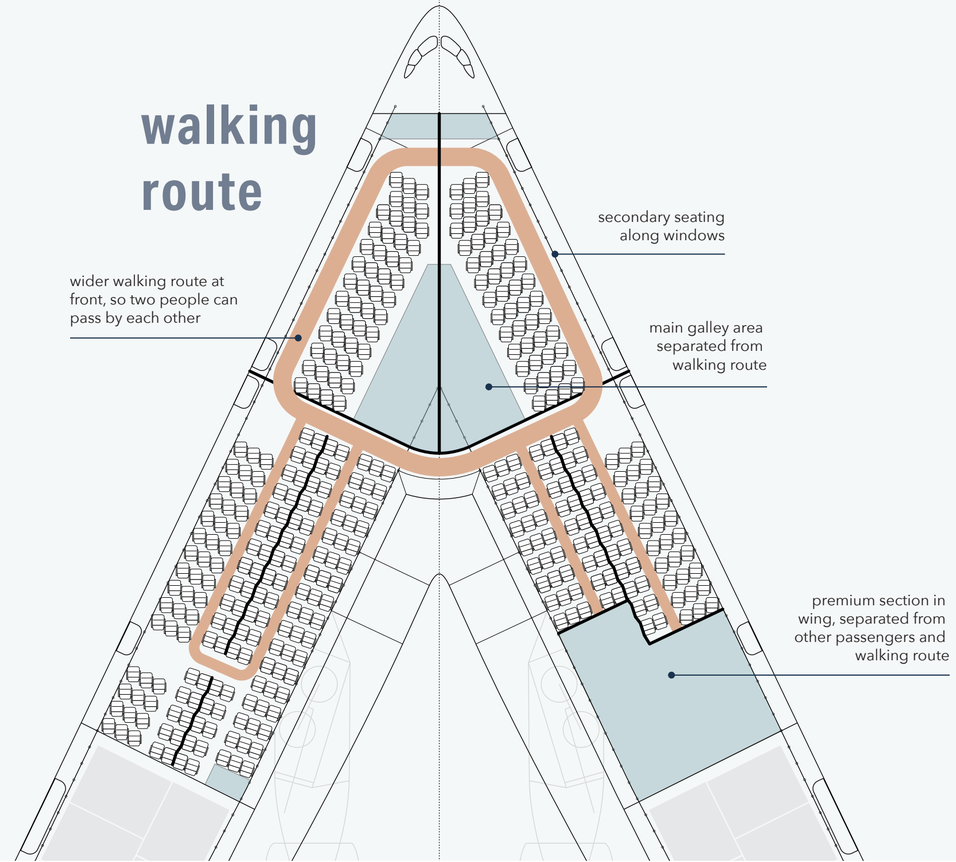


Figure 04-12: proposed floorplan

walking route



04 03

galleys and lavatories capacity and placement

Figure 04-13: preparation of airline carts (Avakian, 2019)

01 / catering procedure: caterer, airline carts, and galleys

Airline meals are prepared by airline caterers prior to a flight. They receive information about how many passengers will be on board, and if there are any other dietary restrictions they need to take into account. After meals are prepared they are placed on trays which are loaded into the airline carts used on board *(figure 04-13)*. These carts are then be transported to the airport where they are loaded onto the aircraft during turnaround and are stored in the aircraft's galleys. Empty carts from the previous flight are de-boarded. (Avakian, 2019)

During the flight, meals can be reheated by cabin crew using the ovens in the galleys and can then be placed back into the carts to serve passenger.

02 / other catering concepts

Traditional galley space can potentially be replaced by more efficient designs and self-service options. For example,Tinie Lam developed a self-service concept for the Flying-V (Lam, 2020). Her thesis describes the development of a self-service bar and separate galley area. This self-service bar allows passengers to acquire their own drinks, while the galley area that holds passenger meals is designed so that the amount to airline carts needed is reduced *(figure 04-14, and 04-15)*. The amount of carts needed is reduced because meals are not stored in carts but in separate compartments. Her proposed design and incorporation into the floorplan contains 3 galley areas, 2 of which located at the rear of the aircraft and one at the front. The two self-service bars are placed at the border between wing and front area, near the main entrances.

new galley design

Per galley:

Box	Content	Subtotal
9x	24 main courses	216
8x	60 starters/desserts	480
1x	space/special meals	various

Figure 04-14: new galley design by Tinie Lam (2020)

self-service bar

Total on board

330 ml cans	30 x 15	450
250 ml cans	30 x 28	840

Figure 04-15: self-service bar design by Tinie Lam (2020)

03 / airline cart dimensions & capacity

In general, aircraft galleys are designed according to standard airline cart dimensions, with ATLAS and KSSU standards being the most widespread (flugzeugmöbel.de, n.d.). Additionally, carts can be divided into two categories: full carts, and half carts, with only the depth of the cart being different. The dimensions of these carts can be seen in *figure 04-16*. ▸

Figure 04-16: airline cart dimensios

> ***Current carts can only carry 35 to 40 packaged meals at a time**, forcing flight attendants to make frequent trips to the galley to restock which, consequently, increases service wait time.*

https://www.zdnet.com/article/on-track-to-a-better-airline-trolley/

> *It depends on the size of the tray. All carts have **14 shelves**. If it is what is called a **half cart, it could have either 14 trays** (which are roughly the same size as the pull down table top) **or 28 trays** which is the size that most charter airlines in Europe use. On my own company's transAtlantic flights, we use the **full size cart with 3 trays on each shelf, that is 42 trays max.***

> *On SQ its **24/36 or 48 depending on the meal served** and also the route.*

> *At CO, **our carts hold 39 meals (internationally) at 3 set-ups per row. 13 rows in each cart.***

> *Here at Hawaiian, there are **30 trays, 30 hot meals and approx. 20 sandwiches per cart.***

Figure 04-17: typical airline cart capacities

https:/t/www.airliners.net/forum/viewtopic.php?t=463241

The meal capacity of these carts determines how many carts are needed during a flight and thus, how much galley space needs to be reserved in the floorplan.

Figure 04-17 gives an overview of different sources (Tramuta, 2012) and (Airliners.net, n.d.) describing how many meals typically fit into one cart.

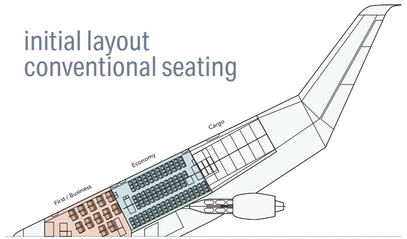
As can be seen, the cart capacity and how meals are divided over these carts vary depending on airline and journey. Generally speaking, the meal capacity for these carts varies between 30 and 42 meals per cart for a full cart.

04 / galley and lavatory count in current layouts

When looking at existing floorplans of the flying-V, the total amount of carts on one flight varies between 40 and 33, with two half carts counted as one full cart. When three meals are served on one flight, and taken into consideration the number of passengers on board, this translates into a meal capacity of 24 and 33 respectively. *(figure 04-18 and 04-19)*

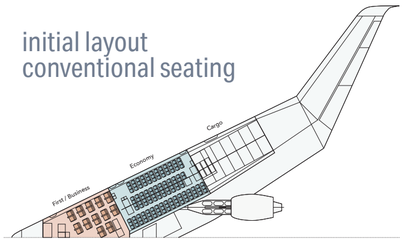
This capacity is on the lower end of the spectrum described in the previous section. This can be explained due to the fact that only actual meals are counted here. Airlines also serve drinks and snack in between meals, which are excluded from these calculations, but do require carts and galley space. This means that to prevent under-capacity, is it wise to use a low cart capacity (comparable to these existing floorplans) when determining how many carts need to be placed in the proposed floorplan. ▸

initial layout
conventional seating



Lavatories		9
Galleys	full carts:	34
	half carts:	12
	total:	40
Cart capacity	passengers:	314
	total meals:	942
	cart capacity:	24

Figure 04-18: galley and lavatory capacity in Flying-V's initial floorplan (TU Delft, n.d.)



Lavatories		9
Galleys	full carts:	34
	half carts:	12
	total:	40
Cart capacity	passengers:	314
	total meals:	942
	cart capacity:	24

Figure 04-19: galley and lavatory capacity in Flying-V's floorplan (R. Vos, personal communications, 15th December 2020)

Galley space needed mainly depends on the amount of passengers on a flight and the amount of meals served per passenger. *Figure 04-20* gives an overview of how many carts are needed if all passengers are served three meals on a long-haul flight.

Because additional food service (like drinks and snacks) is not taken into consideration, a low cart capacity of 30 meals per cart will be used for determining the amount of galley space needed in the floorplan.

For example: if the floorplan facilitates 350 passengers, a total of 35 carts will be needed. If we presume 10 half carts are used for serving drinks and snacks, 30 remaining carts can be used for meal service. 350 passengers equates to 1050 meals (3x350), meaning that these carts need to carry 35 meals (1050/30). This easily falls into the capacity margin described previously.

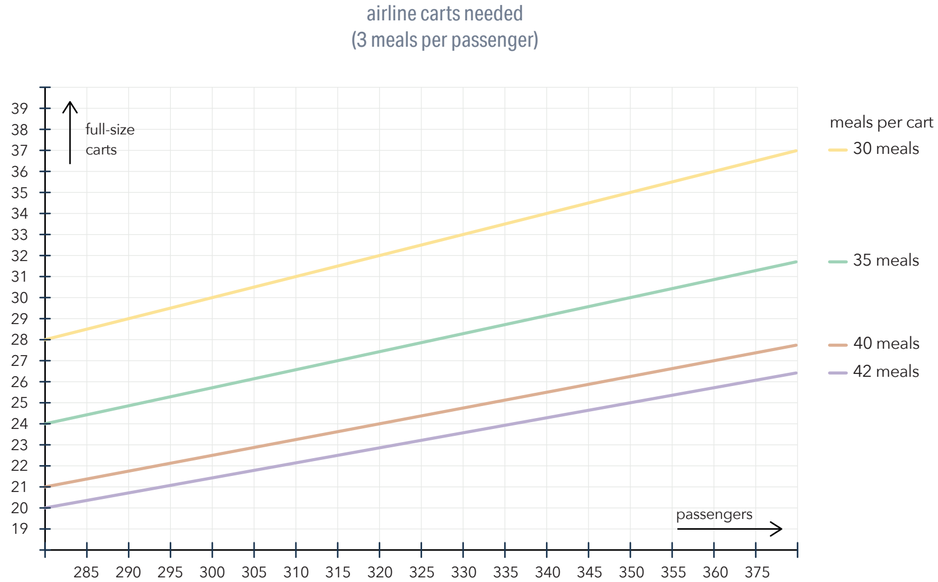


Figure 04-20: airline carts needed for different capacities and amount of passengers

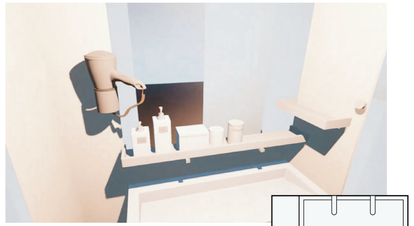


Figure 04-22: refreshment concept by Xinhe Yao

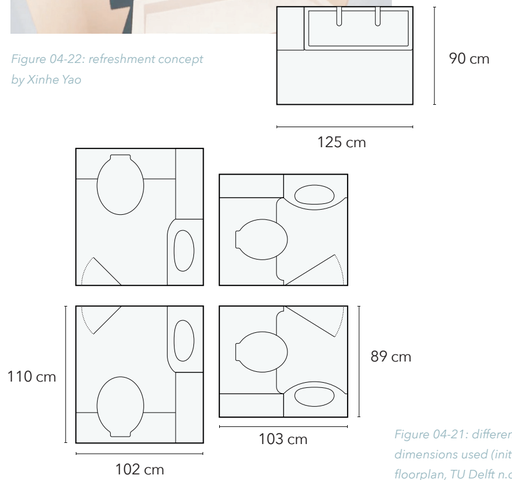


Figure 04-21: different lavatory dimensions used (initial Flying-V floorplan, TU Delft n.d.)

05/ lavatory options and dimensions

Lavatories used in the proposed floorplan have the same dimensions as those used in initial floorplan proposals. An overview of the two designs and their approximate dimensions can be seen in *figure 04-21*. Current floorplans contain around 8 lavatories in total, which will be carried through in the proposed floorplan.

Additionally, a concept developed by Xinhe Yao can be integrated in the floorplan design (Yao, 2019). This concept replaces some lavatories with a hygiene space that can be used by passengers for refreshment *(figure 04-22)*. When concepts such as these are integrated, the minimum number of traditional lavatories used could be decreased slightly. In the proposed floorplan this carries through to around 6 or 7 lavatories, depending on how many refreshment spaces are used.

06/ proposed layouts: placement of galleys and lavatories

Using the additional research described previously, several floorplan propositions were made using varying galley placements and distributions *(figures 04-23 – 04-26)*. The amount of galley space needed was based on the amount of passengers on board, and the estimated amount of carts needed to serve these passengers 3 meals on a flight. Additionally, one proposition was created containing the self-service concept developed by Lam (2020). A section in the rear of the left wing (marked blue) was preserved for premium seating, yet to be incorporated.

A central

central galley and lavatory placements

Components:

lavatories	8	
galley blocks	16 x 2	**32**
passengers	330	33 blocks rec.

Passenger distribution: excl. premium

Left:	individual	71
	couple	28
	group	21
Right:	individual	98
	couple	64
	group	48
Total:		**330**

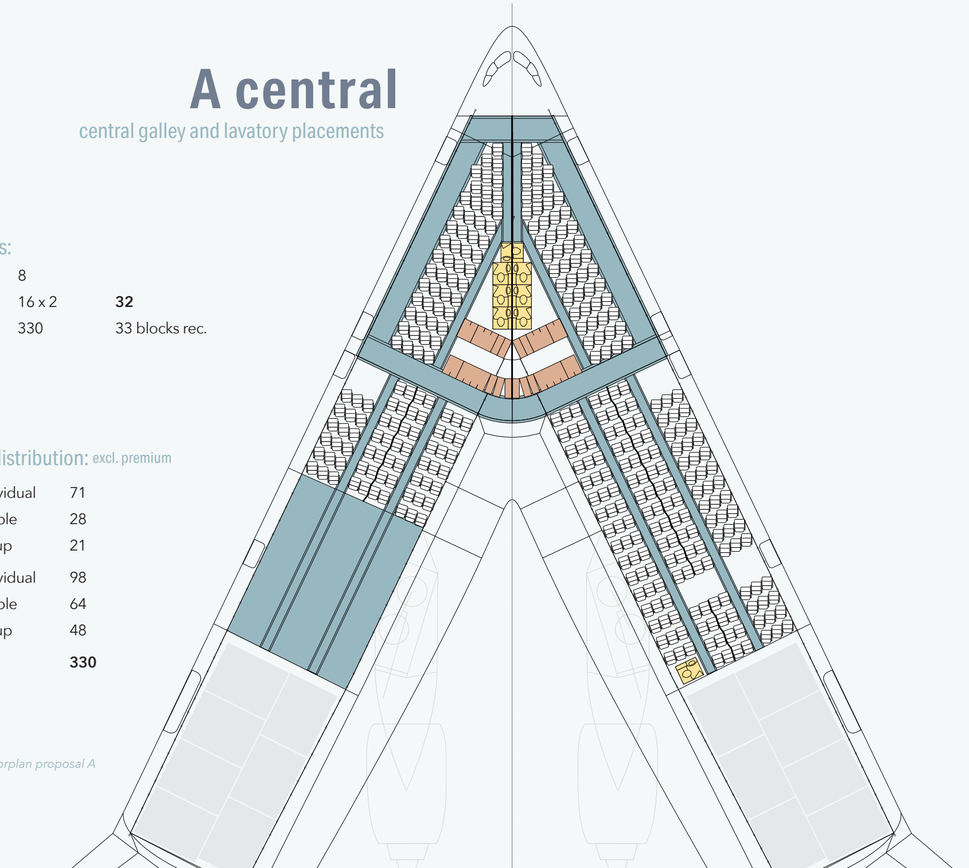


Figure 04-23: floorplan proposal A

B dispersed

two main galley areas, main lavatories at front

Components:

lavatories	7	
galley blocks	7,5+20+3.5	**31**
passengers	315	31.5 blocks rec.

Passenger distribution: excl. premium

Left:	individual	71
	couple	28
	group	21
Right:	individual	98
	couple	52
	group	45
Total:		**315**

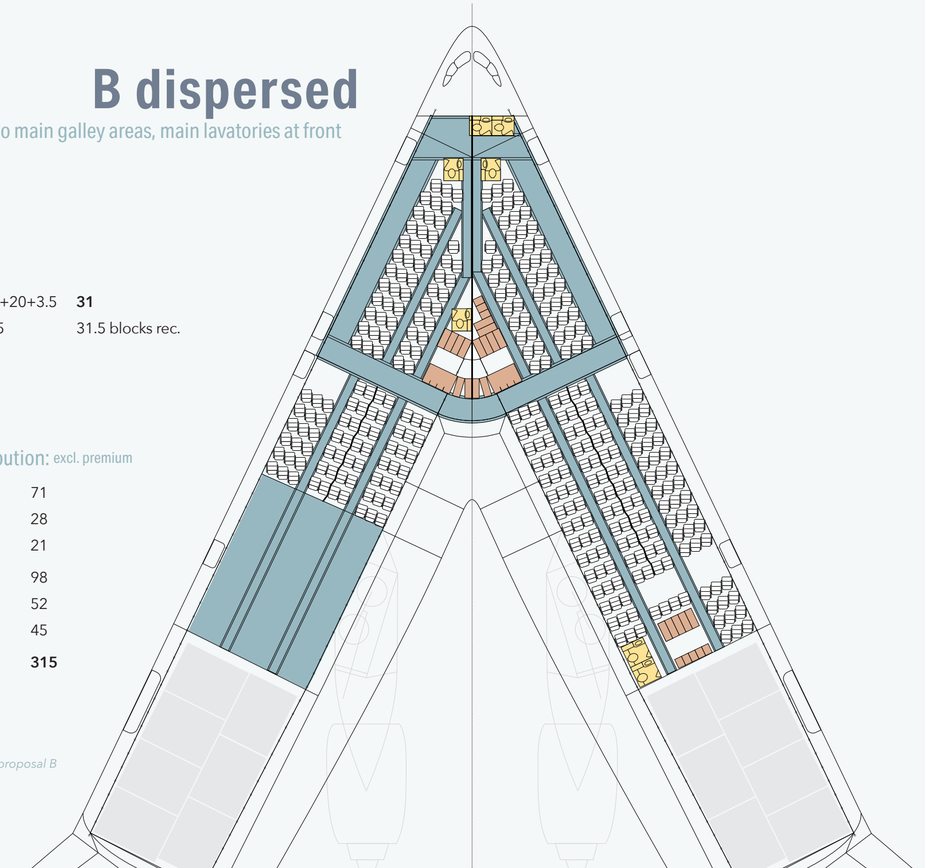


Figure 04-24: floorplan proposal B

C combination

two main galley areas, central lavatory block

Components:

lavatories	8	
galley blocks	24+7,5	**31,5**
passengers	300	30 blocks rec.

Passenger distribution: excl. premium

Left:	individual	65
	couple	28
	group	18
Right:	individual	92
	couple	52
	group	45
Total:		**300**

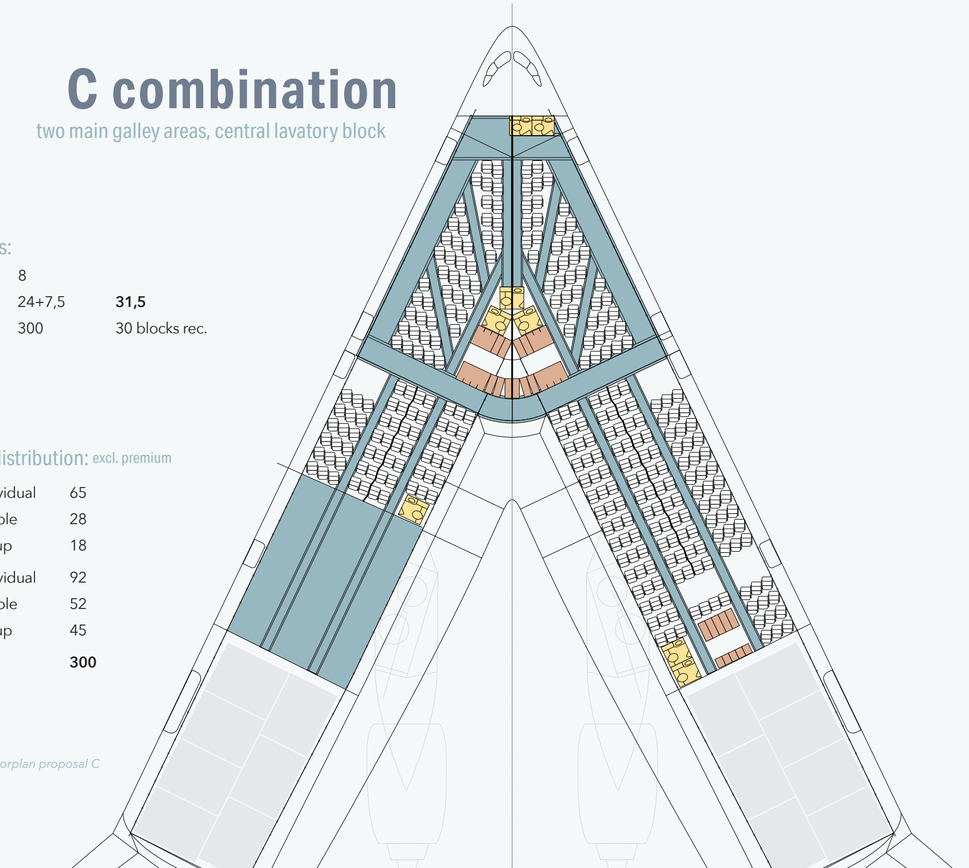


Figure 04-25: ffloorplan proposal C

D self-service

included self-service concepts

Components:

lavatories	8
galley blocks	4,5 galleys, 2 self service
passengers	309

Passenger distribution: excl. premium

Left:	individual	74
	couple	24
	group	21
Right:	individual	98
	couple	52
	group	39
Total:		**308**

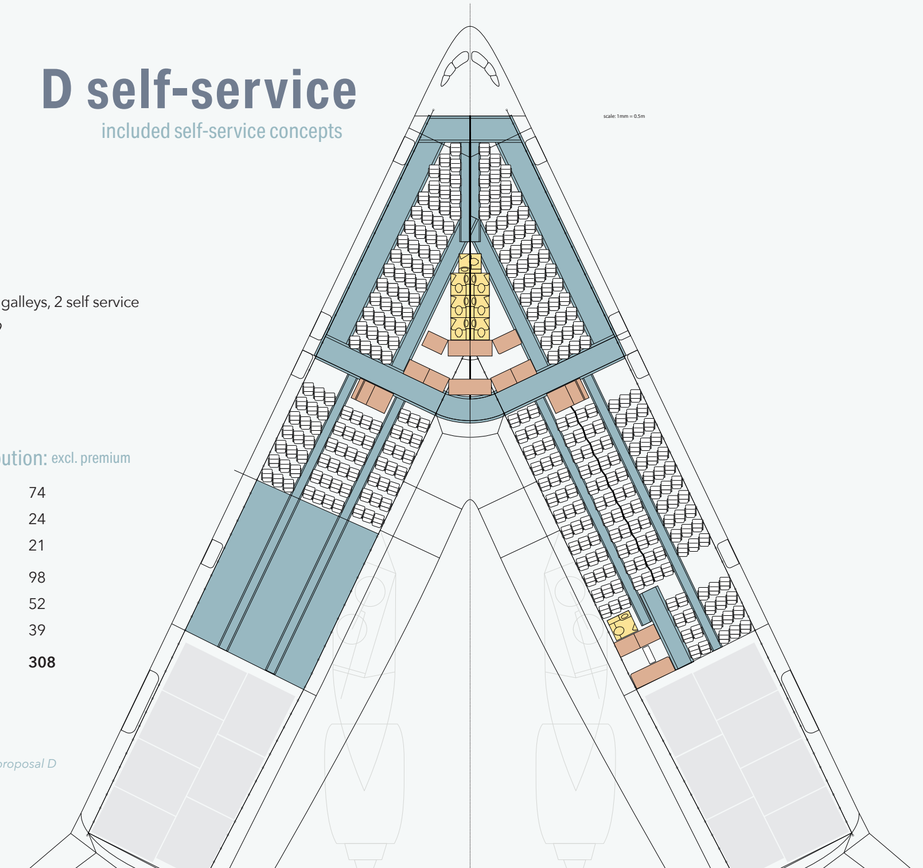


Figure 04-26: floorplan proposal D

Assessment and further layout development

To establish which proposition would be most suitable, additional feedback by a floorplan design expert was acquired. The four proposals were send to Mark Broekhans, Technical Fleet and Arbo Process Engineer at KLM. (Personal communications, June 1st 2021) The acquired feedback resulting from this is described in *figure 04-27*.

After assessing the proposals, it was chosen to use the fourth proposal for further detailing as described in the proceeding chapter *(chapter 5)*. The main reason being that this floorplan differentiates itself by including a self service concept and improved galley design. Additionally, this self-service concept ties in well with the concept of a walking route around the aircraft.

The acquired feedback regarding galley placement and distribution can later be used for improving the chosen proposal. This will be further discussed and elaborated on in *chapter 6: concept evaluation and recommendations*.

A central

central galley and lavatory placements

*There are relatively quite a lot of lavatories for one section. It would be better to spread them across the floorplan so that they are more easily accessible. So less lavatories at the front and more at the rear, separated from the passengers. *This is also the case for the other concepts.

Airlines will check if the aisles width can become less to accomodate for more chairs / passengers

B dispersed

two main galley areas, main lavatories at front

Good that there is a galley at the back, this saves time when serving meals. Beware to not place toilets directly across galleys regaring privacy and hygene issues.

Make sure that the lavatories are not directly opposite the chairs, as passengers don't want to sit here. It is better to place the galley behind the cockpit and move the galleys to the back of this section of the galley.

C combination

galley area in centre and at rear of wing, dispersed lavatory blocks

* see comment proposal 1

Better distribution of lavatories across sections

Figure 04-27: feedback floorplan variations

D self-service

included self-service concepts developed by Tinie Lam

* see comment proposal 1

Great placement (regarding self-service bar), however beware that people walking toward and around the bar doesn't cause too much disturbance for passengers seated nearby.

04
04

additional interior elements

01 / walking route widths

A walking route around the front of the aircraft is created, allowing passengers to explore and see the entirety of the aircraft. This maximises the use of the aircrafts unique shape and layout.

Because the front of the aircraft will become more crowded due to this walking route, the aisles here will have to be wider than the standard minimum aisle width of 38cm. Guidelines for residential walkways state that for comfortably walking, a minimum aisle width of 0.6m and 1.25m is required for walking with one person, or two people side by side respectively (Hordyk, 2010) *(figure 04-28)*,

Because aircrafts generally have smaller walkways, a minimum aisle with of 1m is used for the walking route around the front. It is expected that with this width two people can still easily pass by each other without disturbing passengers seated along the aisle too much. In the wings the standard minimum aisle width of 38cm is used to maximise passenger capacity in this area.

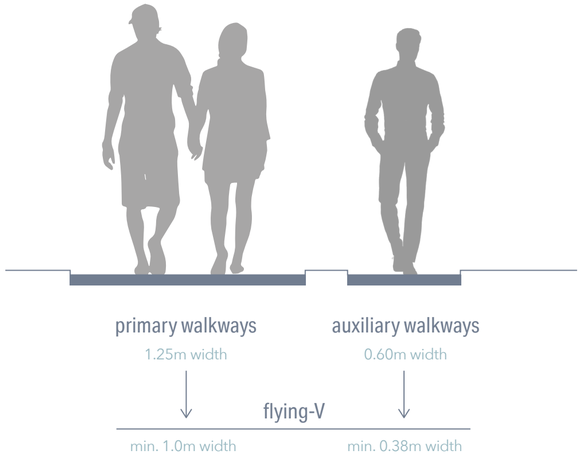
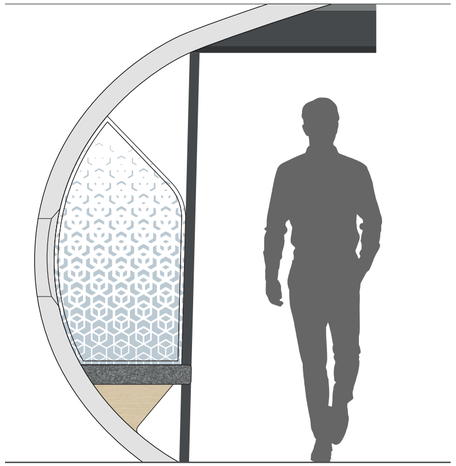


Figure 04-28: aisle widths used for Flying-V floorplan proposal

02 / secondary seating

Secondary seating can be placed along the walking route at the front. Placing secondary seating next to the windows also allows passengers who sit on the windowless side of the aircraft for the duration of their flight, to engage with a window view from the aircraft.
By placing these seats in between the pillars and cabin wall, space that would otherwise not be used by passengers is more purposefully used.

The proposed seat design as can be seen in *figure 04-29* contains a bench along the cabin wall at a height of 50cm and depth of approximately 60cm. This depth however is likely to decrease slightly due to changes in the design of the cabin wall and its thickness. Furthermore, partition walls are placed between the pillar and cabin wall every other pillar (so 140cm apart). This allows passengers to sit in groups of 2 with added privacy, in addition to allowing passengers to sit and rest against the partition wall.



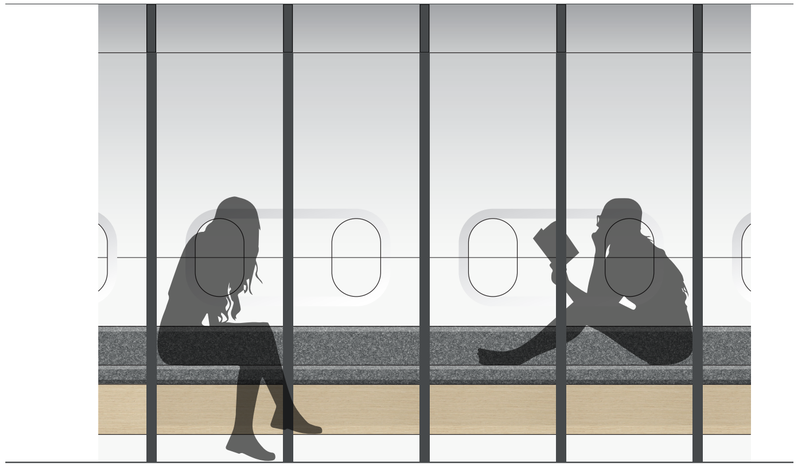


Figure 04-29: secondary seating along walking route, at the front of the aircraft

03 / luggage storage

Luggage storage can be placed above the passengers as well as in the space between the pillars and cabin wall. This is illustrated in *figure 04-30*. Because there is a substantial amount of space between the horizontal beams and cabin roof, the overhead luggage bins could potentially be placed in between these beams. Furthermore, because luggage can also be stored along the cabin wall, less overhead storage might be needed. This might make the top of the cabin less cluttered, creating a more open space.

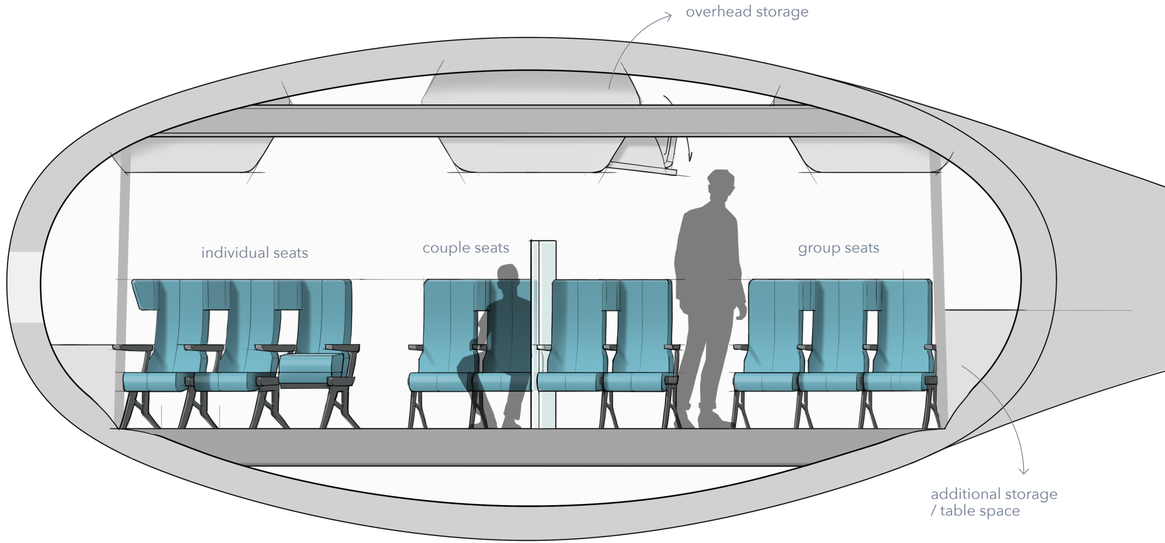


Figure 04-30: proposed section view of the flying-v's wing section

05
00

proposed concept
interior impressions

/ 01 layout

/ 02 seating and sections

/ 03 galleys and lavatories

05 01

layout overview

The aircrafts cabin is divided into several sections as depicted in *figure 05-01*. With the economy and premium cabin sections being accessible to passengers. The cargo areas at the rear of each of the wings and the cockpit area at the front are only accessible to crew. Crew resting areas are located in the cargo area, similar to the floorplan designs described in *chapter 2.1: previous floorplan designs.*

The following chapter illustrates the proposed design of the passenger cabin with regards to its seating configurations and galley and lavatory placement.

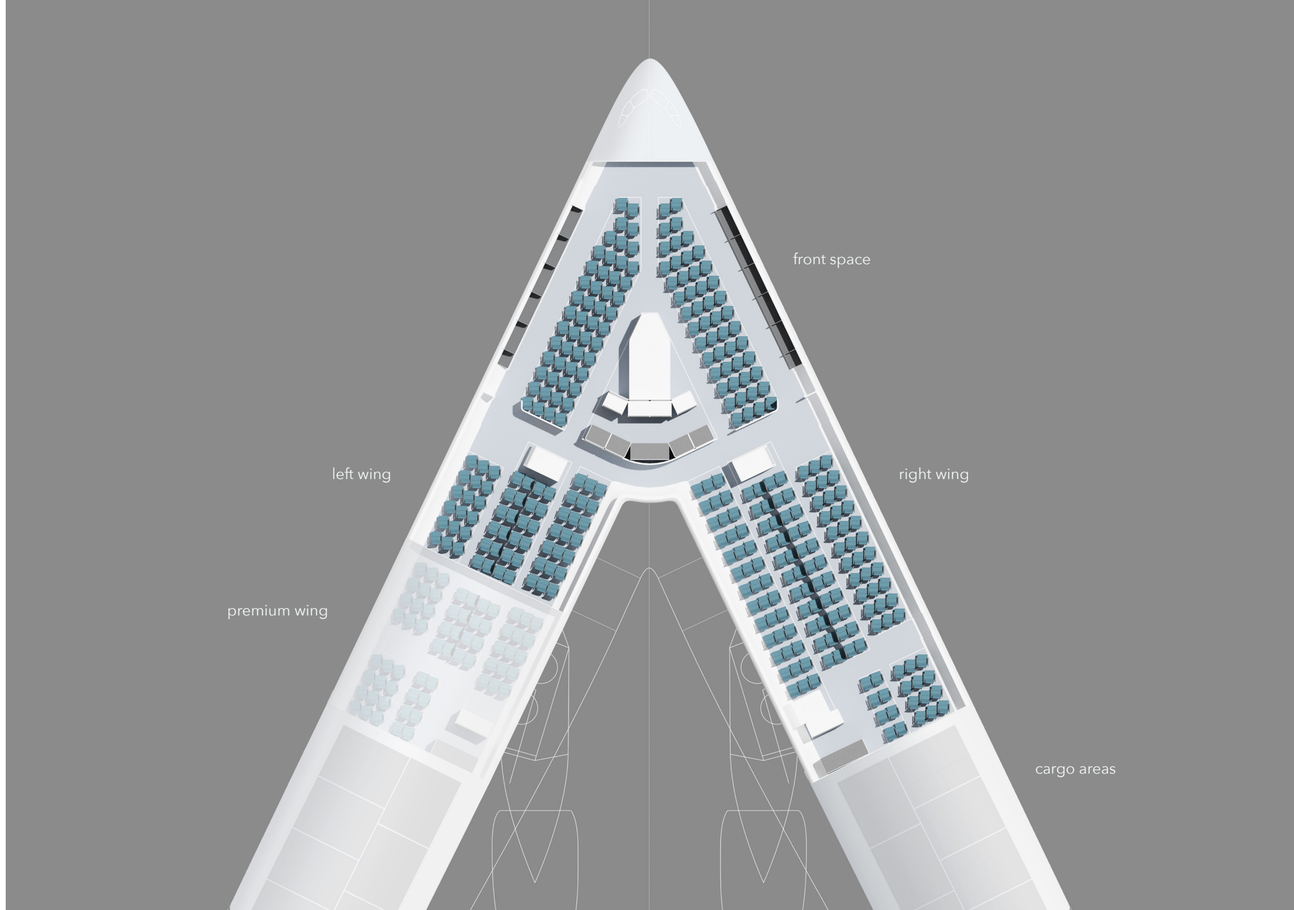


Figure 05-01: layout overview proposed floorplan

05 02

seating and sections

// 01 front space

// 02 wings

// 03 premium wing

// 04 luggage storage

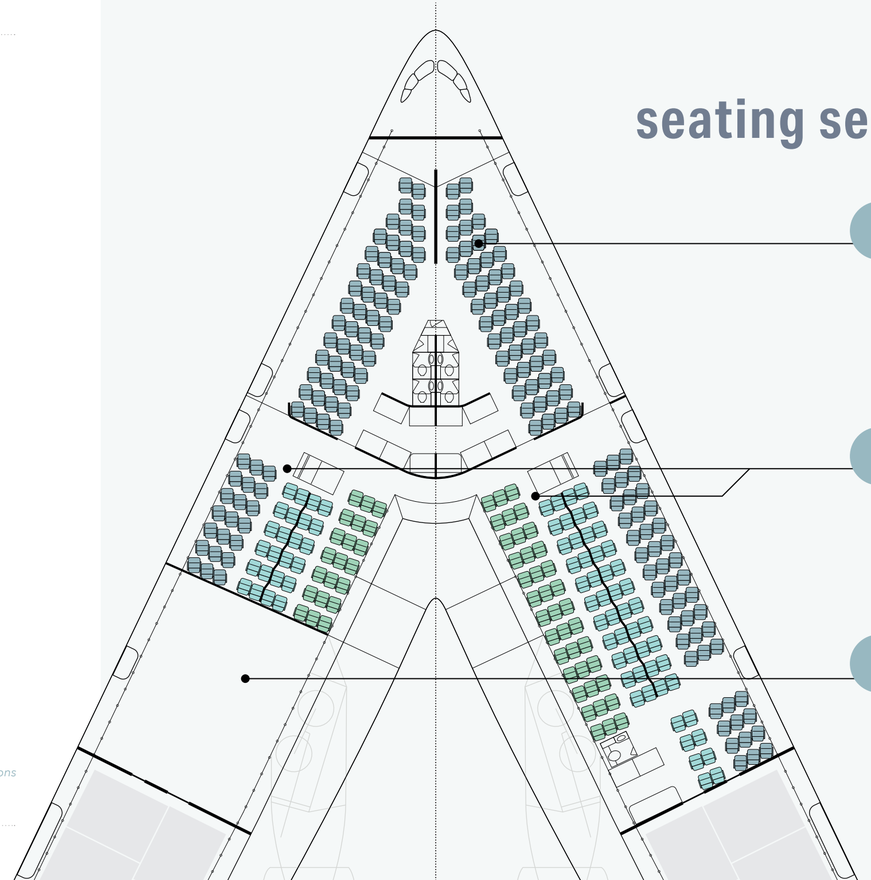


Figure 05-02: seating sections proposed floorplan

seating sections

front space

Large open space at front and main walking route. Contains 102 staggered individual seats and secondary seating.

wings

Wing sections containing three types of seating: individual (69), couple (76) and group seats (60).

premium wing

Premium section: room for approx. 48 premium seats. Scalable depending on required capacity

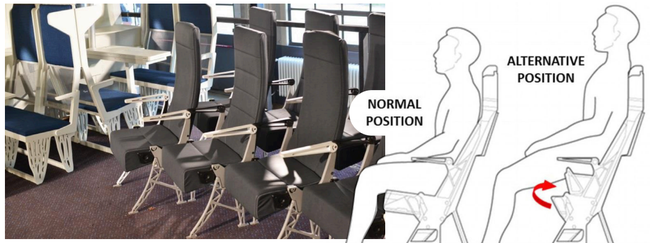


Figure 05-03: Rebel Aero seats in staggered setup

The passenger cabin area can be divided into three sections: the front space, two wings and premium wing. With each section containing different seating configurations *(figure 05-02)*. The proposed floorplan contains 307 economy seats: 171 individual, 76 couple, and 60 group seats. When 48 seats are added to the premium section (13,5% of total), this results in a total of 355 seats.

01 / front space

The front area of the flying-v contains staggered seating which optimises privacy and legroom for individual travellers *(figure 05-04 and 05-05)*. Rebel Aero seats are used across the floorplan. This seat's fold up feature, allows for more easy ingress and egress into the staggered rows. Furthermore, it also allows passengers to sit in a more upright posture when preferred *(figure 05-03)*.

A path around the front of the aircraft allows passengers to walk around the aircraft and be more physically active *(figures 05-06 - 05-08)*. Secondary seating is placed along this walking path, allowing passengers to sit here briefly. *(figures 05-09 and 05-10)*.

Figure 05-04: passenger view from staggered seats in the front area

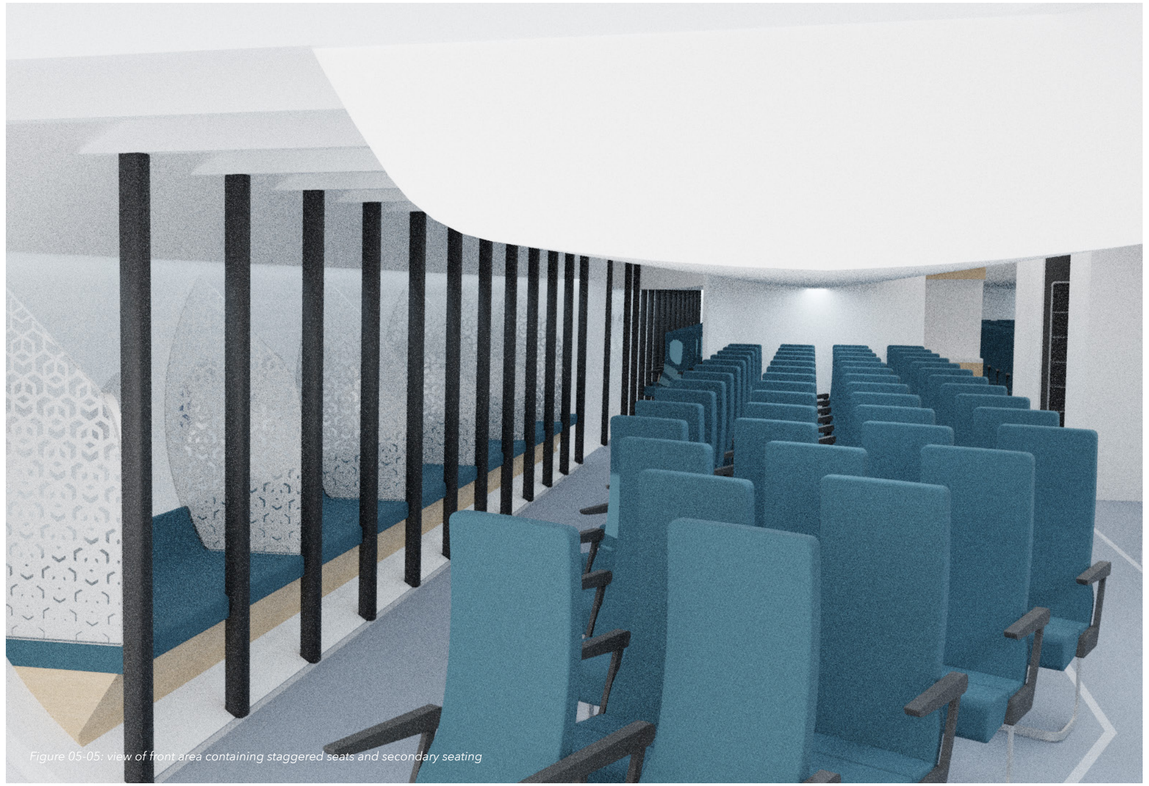


Figure 05-05: view of front area containing staggered seats and secondary seating

Figure 05-06: view from walking route

Figure 05-07: view from walking route

Figure 05-08: view from walking route

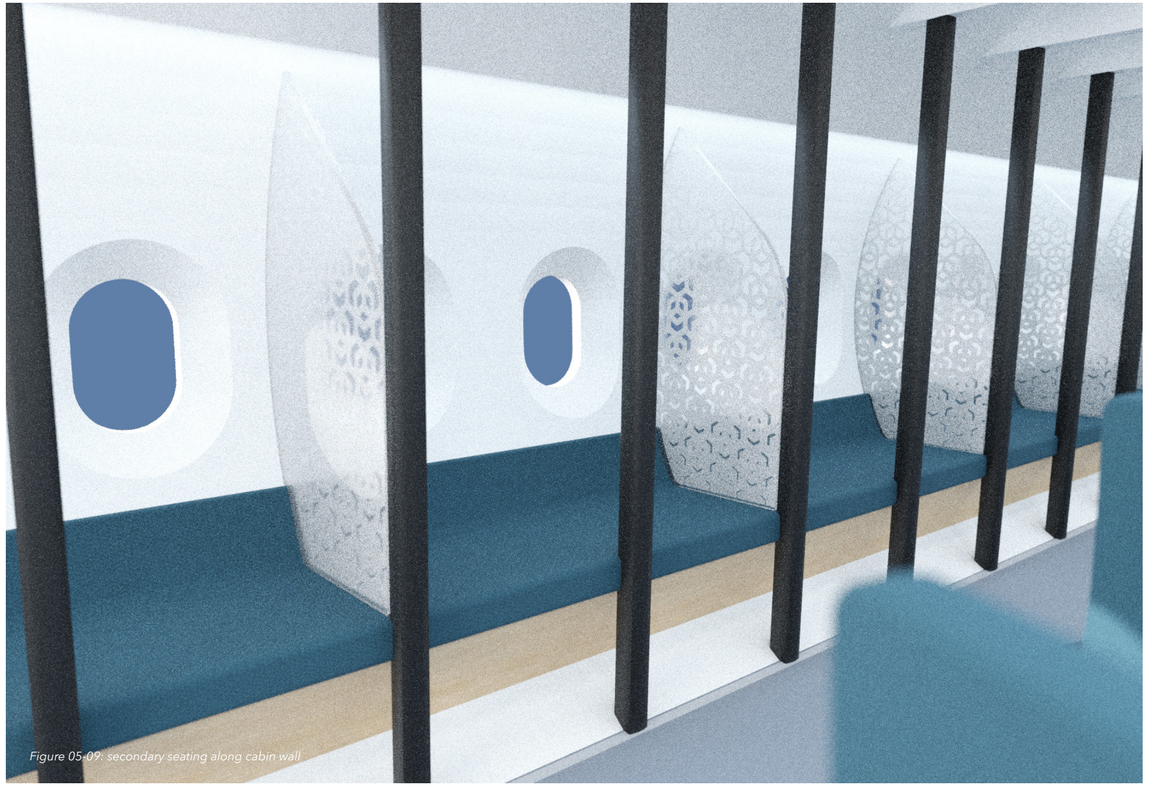


Figure 05-09: secondary seating along cabin wall

Figure 05-10: passenger view from secondary seats

02 / wings

Seating in the wings of the cabin is divided into three different configurations *(figure 05-11 and 05-12).* Staggered seats at 25.5° with a 29" pitch are placed along the window side of the cabin in rows of three. These seat are dedicated to individual travellers who want more individual privacy. The middle rows and rows on the other side of the wing contain minimally staggered seats at 18° and 32" pitch. These seats are reserved for group travellers who prefer privacy within their travel group, rather than individual privacy. A partition wall at a height of 1.3m is placed along the middle rows, creating seating rows of two *(figure 05-13).*

03 / premium wing

A premium area is located at the rear of one of the wings, which separates itself from the economy area and its walking route. This premium area can accommodate approximately 48 premium seats. By moving the dividing wall between the premium and economy area, this space could potentially be increased or decreased depending on airline preference.

04 / luggage storage

Luggage storage can be placed in overhead bins and luggage storage in between the cabin wall and its pillars. *Figure 04-30* in *'chapter 4.4: additional interior elements'* illustrates the possible placement of these types of luggage storage.

Figure 05-11: overview wing section (left)

Figure 05-12: overview wing section (right)

Figure 05-13: passenger view couple seats

05 03

galleys and lavatories

// 01 central galley and lavatory area

// 02 self-service bar and walking route

// 03 rear galley and lavatory area

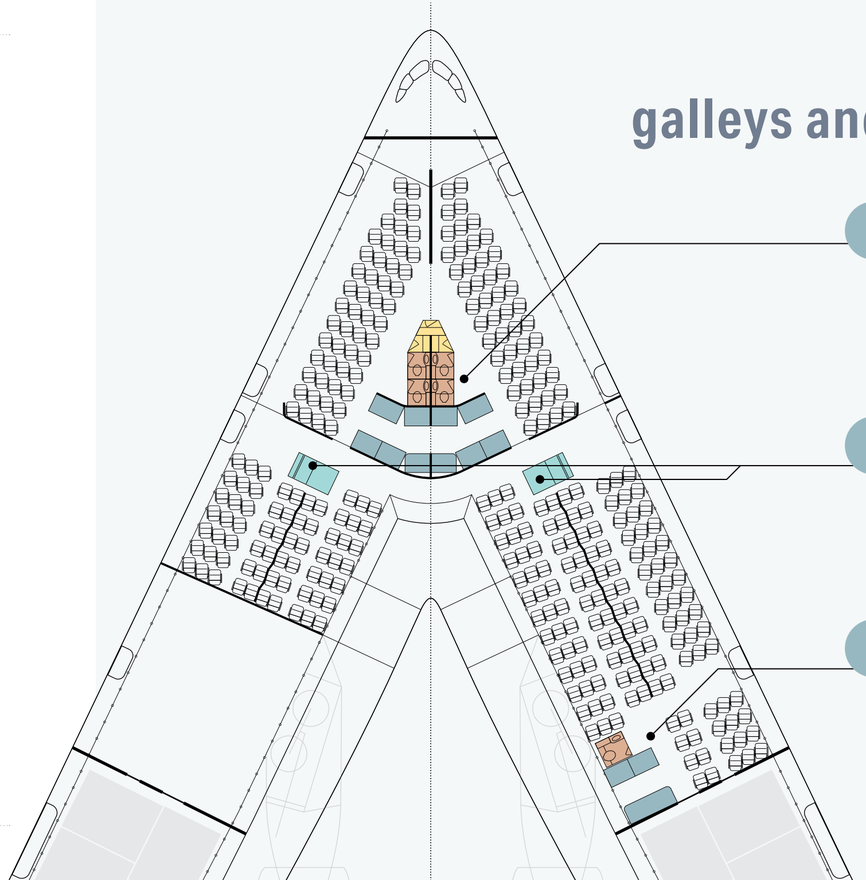


Figure 05-14: galleys and lavatories proposed floorplan

galleys and lavatories

central lavatory / galley block

Galley is separated from the main walking route. Extra room around toilets (4) and refreshment rooms (3) for waiting passengers.

self-service bars

Self-service bar (2) with drinks along main walking route.

rear lavatory / galley

Rear galley for easier distribution of meals. Galley separated from passengers. Toilet separate (1).

01 / central galley and lavatory area

The new floorplan proposal for the flying-v integrates several new galley and lavatory designs. Galleys designed by Lam (2020) are used in the central and rear galley area, in addition to a self-service concept placed along the walking route, in between the wings and front area. The main lavatory area is supplemented by three refreshment rooms as proposed by Yao (2019). Passengers can use these areas for refreshment when they don't require all facilities of a lavatory. This with the aim of reducing waiting times for lavatories.

The aircrafts main galley area is placed at the centre of the front area of the cabin. This area is placed above the main walking route, with the aim of preventing passenger-crew interference. This area could potentially be separated more from passengers through the use of a sliding door or curtains between the aisle and entrance to the galley space *(figure 05-15)*.

The galley area contains 4 meal storage blocks, each with a capacity of 216 main courses in addition to 480 starters and desserts. In total this results in a capacity of 864 main meals in the central galley area. This is enough to serve 288 passengers 3 meals on a flight. Additionally, the area contains 12 ovens and a working area. The galley block's design allows for the storage of airline carts underneath the working area, and space for waste storage underneath the oven blocks. ▸

Figure 05-15: central galley area

The lavatory area that is located above the galley space contains four lavatories and three refreshment rooms *(figure 05-16)*. The central placement of the lavatory block allows for extra space for passengers who are queuing for the use of lavatories *(figure 05-17)*.

Figure 05-16: sideview impression lavatory and refreshment area

Figure 05-17: space around central lavatory area

02 / self-service bar and walking route

Two self-service bars are located along the walking route *(figure 05-18).* They are placed between the front area and wing so that they are easily accessible to passengers in both areas. Each self-service bar has a capacity of 1290 canned drinks, in addition to two coffee / tea machines. In total this equates to 2580 canned drinks on the aircraft (Approximately 8 per passenger)

Figure 05-18: self-service bar along walking route

03 / rear galley and lavatory area

Next to the central galley area, another meal storage and oven block is located at the rear of the wing. This allows for easier distribution of meals by crew. This galley block contains 216 main courses, a working area, and 5 ovens. By placing the galley at the edge of the cabin instead of the middle, passengers are less likely to walk through or into the galley space.

An additional lavatory is located above the galley space, easily accessible for passengers seated at the rear of wing *(figure 05-19).*

Figure 05-19: rear galley and lavatory area

06
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concept evaluation and recommendations

/ 01 requirements evaluation

/ 02 recommendations

06 01

requirements evaluation

In order to determine the validity of the proposed floorplan and acquire possibilities for further improvement, the proposed concept was assessed using the traffic light method (described in *chapter 3.3*) and the list of requirements as described in *chapter 3.4: design goal*. The full assessment sheet can be found in *appendix E*. *Figure 06-01* gives an overview with elaborations on the points that need additional research and/or design solutions.

Passenger capacity & distribution	The floorplan should allow for at least 300 passengers. This includes both economy and premium passengers	
	At least 13% of all seating should be premium class (first and business or combined)	
Galley & lavatory capacity & distribution	The floorplan should allow for sufficient space for the amount of galley carts and/or additional self service concepts needed defined by the number passengers on board.	
	The floorplan should allow for at least 8 lavatories with a passenger capacity between 300 and 350. Or a minimum of 6 if other lavatory concepts such as a refleshment area are included.	
Passenger comfort	Passenger comfort in relation to legspace and privacy should be increased compared to average economy seating. · A minimum seat pitch of 31", or a pitch with similar comfort scores for staggered seating. · At least one design measure should be taken to improve privacy for individual, couple and group travellers.	
Seating configurations	Passenger seats that are used during take-off and landing should not be angled more than 18° from DOF.	
	There should be no less than 2 passenger seats in-between a passenger seat and an aisle.	
Crew comfort & concerns	Galley areas should not be placed along the main walking route for passengers	
	There should be a minimum of 8 crew seats included in the floorplan	
	There should be a dedicated resting area for crew in the main cabin or front of cargo area	
Aisle width	The main walking route should have minimum aisle width of 1.8m (or 2m check this!)	
	Aisle width should not be smaller than 381mm below 640mm height, and 508mm above 640mm height.	
Emergency exits & routes	Emergency exists should be directly accessible from the neighbouring aisle, without seats or other interior elements obstructing the path.	

The exact size of the premium area of the floorplan is not yet determined. With a economy capacity of 307 seats this area should allow for a minimum of 45 seats.

When the recommendations as described under *chapter 6.2: Adjustments to placement of galley and lavatories,* are carried through. The galley area at the front of the aircraft will border the main walking route. It is therefore recommended to place the entrance to this galley area not directly along the walking path, or research how much crew-discomfort this causes.

The exact size of the premium area of the floorplan is not yet determined. With a economy capacity of 307 seats this area should allow for a minimum of 45 seats.

It is recommended to place the resting area for crew members in the cargo area, similar to the initial floorplan proposals as described in *chapter 2.1: previous floorplan designs*

Figure 06-01: requirement evaluation and subsequent recommendations

06 02

recommendations

Based on this assessment, several recommendations for improvement can be formulated. These will be further elaborated on below.

01 / adjustments to placement of galleys and lavatories

As described in *chapter 4.3.6: proposed layouts (p. 166),* several adjustments should be made to the placement of galleys and lavatories, mainly in the front of the aircraft. Assessment by a floorplan expert showed that its better to have a more distributed placement of lavatories across the aircraft. Additionally, recommendations were made regarding the placement of galleys. For safety of cockpit crew, it is better to place galleys directly behind the cockpit entrance, as this will prevent passengers from entering this area. ▸

By making the following adjustments for example, the placement and distribution can be improved *(figure 06-02)*:

- Moving the central galley to the front of the aircraft, behind het cockpit entrance. When doing this, some seats located at the front of will have to be removed.
- Moving the lavatory area down to the place of the abovementioned galley area.
- In case of the above: placing the seats in the front area in a configuration as suggested in *floorplan variation B (p. 163)*, can help fill up the space created by moving the galley and lavatory area.

Furthermore, in the current proposed floorplan, the rear galley area is located in the passenger area. Because the cargo area of the aircraft is located at the rear, this galley could be moved to the cargo area to separate it from passengers.

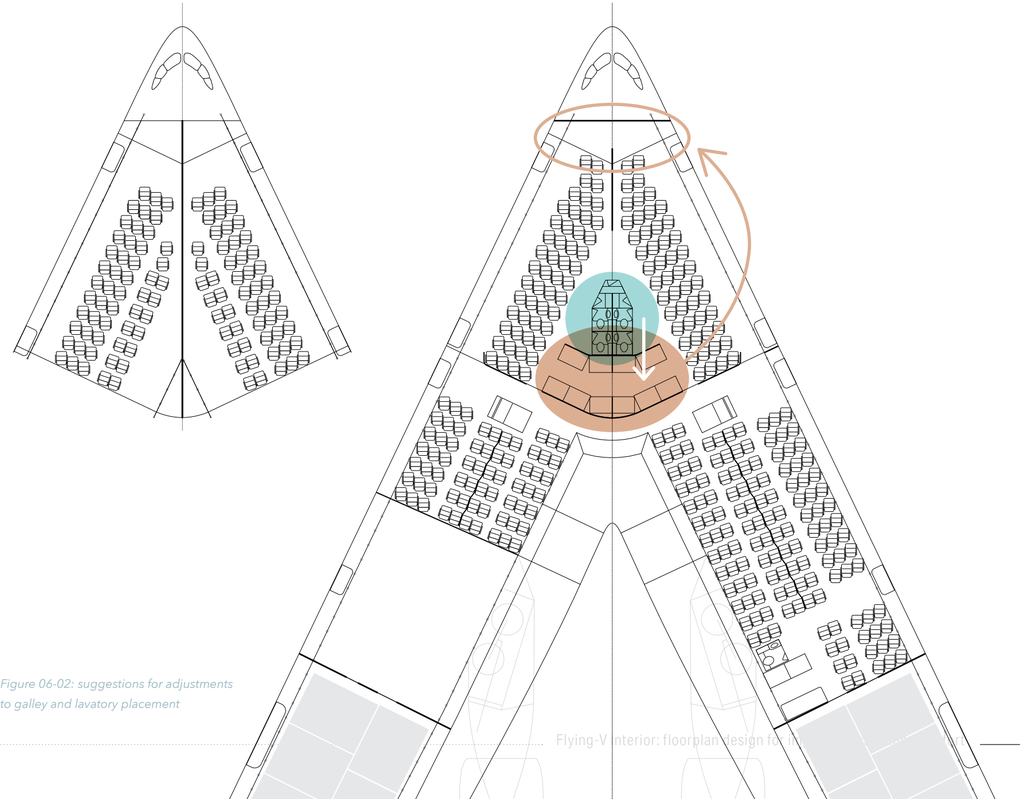


Figure 06-02: suggestions for adjustments to galley and lavatory placement

02 / increasing pitch to improve comfort

To further improve passenger comfort with regards to legroom, the pitch of each of the seating rows can be increased. *Figure 06-03* gives an overview of the floorplan and capacity when the pitch is increased to 31" for staggered seats and 34" for minimally staggered seats. With similar comforts scores of 7,9 comfort score (Liu, 2021), and ~8 (Anjani, 2020) respectively.

The example shows 288 economy seats, but without seats placed in the premium area. This means that if 28 seats can be placed in the premium area, the minimum of 300 seats can be reached. In that case however, the premium area does not account for more than 13% of all passenger seats as described in the requirements. Therefore, adjustments will have to made to the size of these areas to reach the preferred distribution.

03 / effect of proposed floorplan on exterior

In order for the proposed floorplan design to work most effectively, several adjustments to the exterior and structural design of the aircraft are suggested.

Firstly, the bulkheads (structural walls in the interior) as described in *chapter 2.1.4: cabin interior – features and geometry (p.32)* were moved up slightly to optimise the walking route around the front of the aircraft and separate it from the main galley area. It is therefore important to discuss with the aircraft's engineers whether this is feasible. If not, adjustments should be made to the walking route that still allow it to be sufficiently separated from passengers and crew to prevent disturbance. Additionally, as a result of moving this wall, the two main doors along these walls were also moved up slightly. ▸

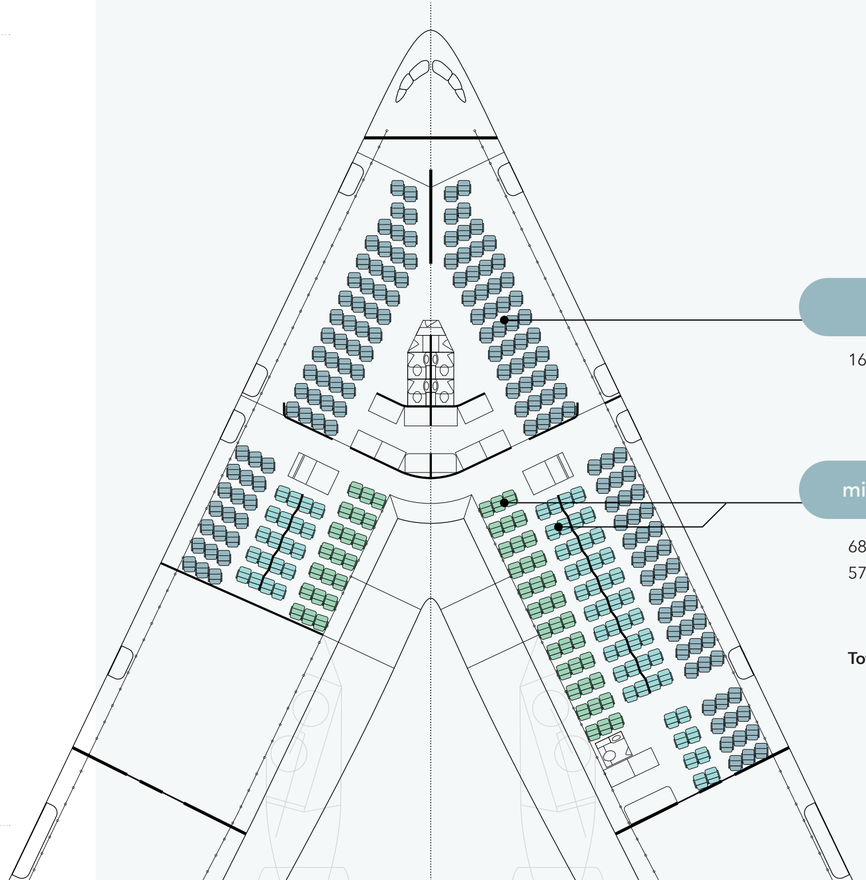


Figure 06-03: floorplan and corresponding capacities when pitches are increased to 31" and 34".

Lastly, it is recommended to adjust the distance between the pillars so that they are always in the same location relative to the seating rows (for example the same distance as the seat pitch used: 29" or 73.66 cm). This way, the seats can be placed so that the pillars do not interfere with the passengers legroom.

04 / possibilities for travel class distribution

In the current proposed floorplan, the exact placement and design of the premium area is not yet determined, only the general placement of the area at the rear of one of the wings is shown. The size of this area however, can easily be adjusted depending on the capacity and space needed. It is recommended to leave space for approximately 48 premium seats in this area, around 10-15% of the total capacity.

Additionally, some seats in the proposed floorplan have more legroom because they are bordering an aisle or emergency exit. It can be considered to mark these seats as premium economy seating and book them for a higher price. What needs to be taken into consideration however, is that some of these seats are also close to galley areas and lavatories, which some passengers might not prefer.

05 / integrating other concepts

Several opportunities are present for the integration of additional seating concepts.

Firstly, groups seats that are facing each other can be created by turning around seats in the middle rows or rows on the windowless side of the wings. This way, seating groups for more than 3 passengers can be created. Additionally, when done with seating along the main walking route, disturbance by passengers walking along the route or getting drinks from the self-service bar located along this route can be prevented *(figure 06-04)*.

Secondly, in the current proposed floorplan, a partition wall is placed along the centre of the middle rows. However, this partition wall can also be placed in such a way to create seating groups of 1, 2 and 3 passengers. Similar to the shifted seats described in *design direction 1: shifted rows*.

Group seating alternatives

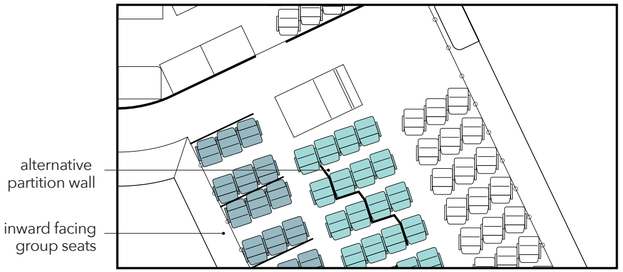
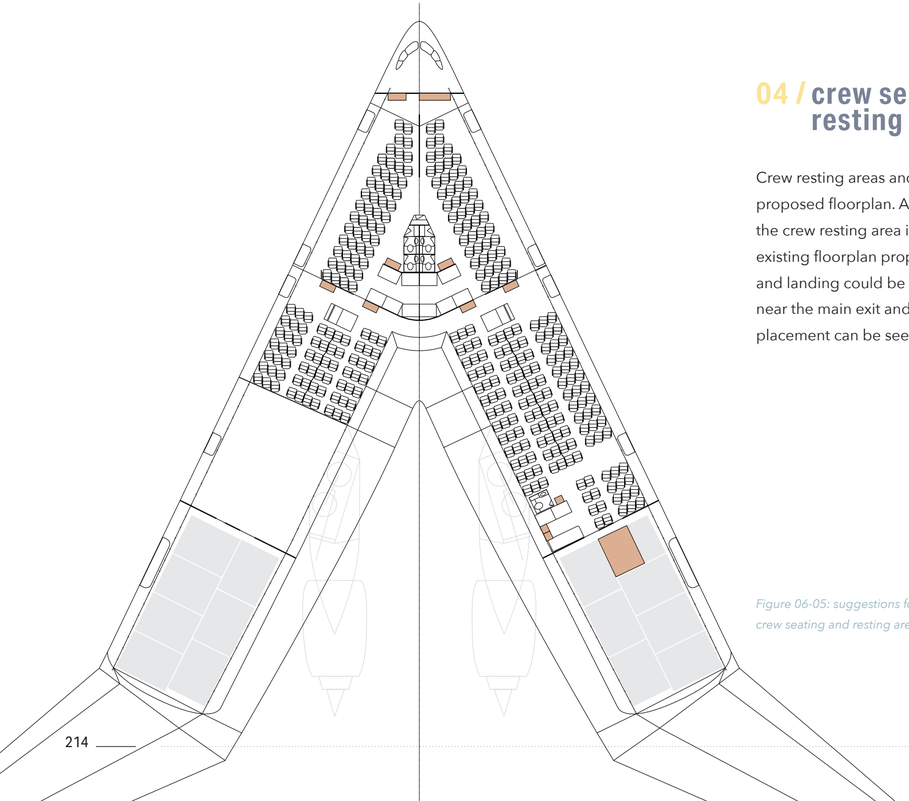


Figure 06-04: suggestions for alternative group seat configurations

Lastly, in order to improve sleeping comfort on the aircraft, concepts such as the flatbed concepts described in *chapter 3.1.3: previous seating concepts*, could be added to the floorplan. It is however recommended to place these flatbeds at the rear of the wings to prevent disturbance by passengers walking around,



04 / crew seating and resting areas

Crew resting areas and seating are not yet defined in the proposed floorplan. An attractive option would be to place the crew resting area in the cargo hold, as is the case with existing floorplan proposals. Crew seating, used for take-off and landing could be placed in the galley areas or areas near the main exit and entrances. Examples of possible placement can be seen in *figure 06-05*.

Figure 06-05: suggestions for placement crew seating and resting area

04 / recommended additional research

Due to the scope of the project, not all aspects of the floorplan could be extensively researched or proven to be desirable and viable. Several recommendations can be made for additional research.

Firstly, galley placement and ease of use for crew regarding the placement hereof could not be proven effective yet. It is therefore recommended to research whether entering and exiting the galley areas is pleasant enough.
Furthermore, additional research needs to be done into the distribution of galleys along the aircraft and ease of serving with regards to this.

Secondly, the current floorplan contains partition walls along the middle rows of the wings. It is not yet determined whether this causes safety concerns in case of emergency. Research needs to indicate that passengers can exit the aircraft in a timely manner when this design is in place. Similarly, the areas around the exists of the aircraft are not yet proven to be sufficient enough. These areas are now free of seats and directly border at least one aisle, however it is not proven that this is sufficiently in line with safety regulations. Contrarily, less empty space might be required here, allowing capacity to be increased.

Lastly, in the current design, seats are placed near the self-service bar and along the walking route. It would be recommended to research whether this causes discomfort for passengers seated here, and if the case to which extent this discomfort is acceptable enough or how this could potentially be solved.

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Lisa Wamelink

MSc. Integrated Product Design

Faculty of Industrial Design Engineering

Delft University of Technology