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Aero

# Memo

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# Family Concepts of Box Wing Aircraft

**Contents**

# Symbols

| | |
|---|---|
| $A$ | aspect ratio |
| $C_L$ | lift coefficient |
| $S_w$ | Wetted surface area |
| $E_{max}$ | Maximum Glide Ratio |
| $C_{L,m}$ | lift coefficient at maximum glide ratio |
| $C_{L_\alpha}$ | lift curve slope |
| $k$ | free parameter |
| $i$ | incidence angle |
| $M$ | Mach number |
| MAC | Mean Aerodynamic Chord |
| CG | Centre of Gravity |
| $\mathrm{V_m}$ | Velocity at maximum L/D ratio i.e minimum drag |
| $\mathrm{V/V_m}$ | Ratio of aircraft speed with minimum drag speed |
| $\mathrm{C_V}$ | Tail volume coefficient |

# 1 Background

For an aircraft project to be successful it is mandatory to have a family of aircraft based on one basic version. In industry it is standard practice to add/remove fuselage sections to/from the basic fuselage, thus stretching/shrinking the aircraft. It is desired to use the same wing for all of the family members so that development and production costs can be kept minimal. The same should apply to box wing aircraft. Below is a detailed description of the steps taken to propose the versions with their General Familiarization diagrams for both *Single* and *Twin* aisle Box Wing concepts respectively.

Furthermore it is important that ground handling requirements are taken into account from the very beginning in aircraft design activities. The aircraft needs to be designed such to allow for sufficient space around the aircraft for all ground service equipment. The updated terminal servicing for the new proposed Family concepts has been discussed. Throughout the project findings, Airbus A320 family was used as reference including the Airplane Characteristics for Airport Planning document for A320 **[Airbus 2011]**. In addition findings were also presented to Airbus Engineers for feedback and refinement. As a supplement to this memo, provided are the necessary data files for future reference.

# 2 Method

## 2.1 Initial Problems

When analyzing a feasibility of Box Wing family it is important to note the various changes that occur to the base design. The wing layout including sections where the various wing surfaces connect the fuselage must be kept consistent and untouched to that of the base version. This is because sections may not be added to areas where wing box/landing gear box lie. Only constant area cylindrical sections (plugs/frames) may be added to parts of the base design.

To keep the wing layout the same and compensate for change in aircraft weight, landing field length is varied, as well as the ratio of speeds at minimum cruise drag ($V/V_m$) to obtain appropriate performance matching charts. Spreadsheets that used first principles **[Schicktanz 2011** and **Scholz 2008**] have been updated with these steps for newer proposed family.

One important dimension that changes due to the stretch/shrink of the fuselage is the longitudinal distance between the MAC of the forward wing and the aft wing. This is denoted by l‘. This parameter was also varied to meet a safe operating CG envelope. Further studies were conducted to understand the CG shifts. Large CG shifts entails large variations in stability and maneuvering margins which result in tail plane editions. With a change in the CG location due to the new fuselage dimension this downward force from the tail plane has to be increased/decreased (especially during shrinking fuselage) and hence resulting in a different tail plane dimensions **[Torenbeek 1982]**. This is a major restriction due to the use of a V-tail which acts as both the vertical and horizontal stabilizer. The use of a V-tail however provides some advantages when compared to a conventional tail assembly. Fewer fuselage tail junctures means less drag as well as a lower tendency for rudder lock. It is also suggested that large-chord control surfaces may be required to keep the control forces equal to or greater than those of the conventional tail assembly **[Purser].** The V-tail on both stretches (V100 and V200) encounters lower $C_V$. Typical values for commercial jet transport lie at 0.09- 1.00 **[Raymer 1992]** however the obtained values are around 0.081 etc.

Another minor problem is the length l‘ which if too large may add to Flutter phenomenon as well as issues related to resulting divergence [**Bisplinghoff 1996**]. A detailed aerodynamic and aeroelastic study has to be completed once wind tunnel testing begins and the designs are advanced.

## 2.2 PreSTo and Detailed Methodology

Using the steps involved in the preliminary sizing, cabin and fuselage layout proposed by Shicktanz and Scholz and the use of *Aircraft Preliminary Sizing Tool* (PreSTo) **[PreSTo 2011]**, four new family members were introduced. They are based on the industry standards for seating capacity and referring to the Airbus 320 family (especially for the single aisle aircraft). The following details form the basis of the new family:

- *Twin* Aisle
    i. V100 – 178 Seating Capacity
    ii. V200 – 218 Seating Capacity
- *Single* Aisle
    i. S100 – 126 Seating Capacity
    ii. S200 – 178 Seating Capacity

The preliminary sizing sheets were varied for Passenger capacity, and PreSTo generates the updated fuselage **[Scholz 2008]**. Dimensions of tail and nose sections are kept the same when using this tool. Cabin layout is varied to match that of the base version. Once the new cabin is created, l‘ is varied to stay at safe operating CG as well as keeping wing boxes at original position to that of base. The sizing sheet has been updated so that upon changing l‘, the V-tail stays at the same location as that of the base versions, i.e. only the forward wing moves. This should make it easy for future updates to family concepts if need be. CG locations are estimated using the diagrams generated as well as information received from the various sizing sheets. Placement of landing gear box and engine are all dependent on the CG position and hence are always kept consistent with that of the base version.

In order to keep the wing area unchanged, landing field length is varied, depending on the change of weight which naturally if increased, a longer take of run will be required. The ratio of speeds at minimum cruise drag ($V/V_m$) is also adjusted for performance matching chart to reach design point.

$$\boxed{C_L / C_{L,m} = 1 / (V / V_m)^2} \qquad (1)$$

Eq.1 forms the basis for this optimization to reach design point and helps one find the coefficient of lift at maximum glide ratio or minimum drag. This in turn changes the two basic optimization variables (thrust to weight ratio and wing loading, given by equations 3 and 4 on the next page) Further details on performance matching can be found in *A short course to Aircraft design* **[Scholz 2010]**

$$\boxed{E = E_{max} \cdot \frac{2}{\dfrac{1}{\left(\dfrac{C_l}{C_{l,m}}\right)} + \left(\dfrac{C_l}{C_{l,m}}\right)}} \qquad (2)$$

$$\boxed{\frac{T_{TO}}{m_{MTO} \cdot g} = \frac{1}{(T_{CR} / T_0) \cdot (L / D)_{max}}} \qquad (3)$$

$$\boxed{\frac{m_{MTO}}{S_W} = \frac{C_L \cdot M^2}{g} \cdot \frac{\gamma}{2} \cdot p(h)} \qquad (4)$$

**[Scholz 2010]**

To keep the error for the mass estimation low i.e. calculated mass vs. PreSTo, relative operating mass ($m_{OE}/m_{TO}$) is altered in the sizing sheet within the aircraft mass and centre of Gravity spreadsheet. More details for this can be seen on the sizing sheet for each family concept. The above steps should successfully allow for the same original $S_w$ of base versions.

## 2.2.1 Twin Aisle

At first it is not possible to shrink the fuselage base version. Based on the reduction of seating capacity for a shrinked version, the fuselage length would be too small to have all the necessary components of the box wing. This was checked for a seating capacity of 120. Hence, the twin aisle provides options for stretches of base version only. As the seating capacity increases, emergency exits must also increase, to comply with certification rules. PreSTo also recommends the number of exits, however their placement is done manually. The distance between exits may not be lower than 60 feet **[PreSTo 2011]**.

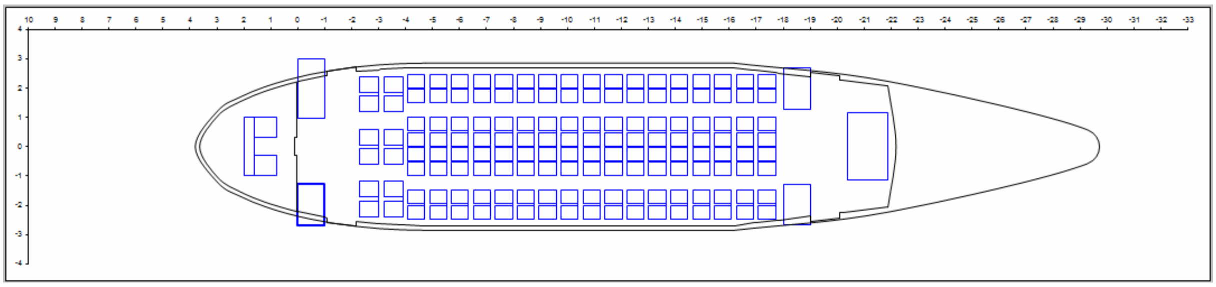


**Figure 1** Twin Aisle Base version generated by PreSTo Cabin **[Scholz,Schiktanz 2011]**

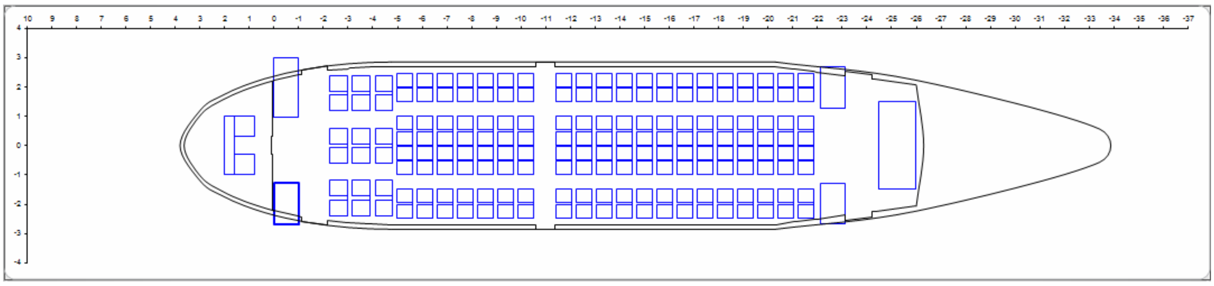


**Figure 2** **Twin Aisle –V100** 178 seating capacity version generated by PreSTo Cabin

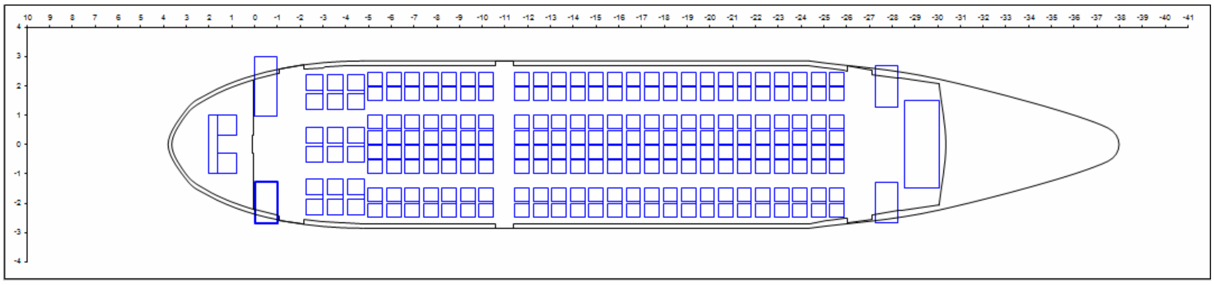


**Figure 3** **Twin Aisle – V200** 218 seating capacity by PreSTo Cabin

Figure 2 shows the final cabin layout for V100. A row has been added to first class with seating capacity here at 18 and keeping number of passengers in the economy class to 162. Two Plugs were added, one in front of the forward wing and the other to incorporate the exit (type C, floor level). The former consists of 2 frames and the latter with 5 frames respectively. Similarly, for the V200 (Figure 3 cabin layout), two plugs in between the forward and aft wings are added. General Familiarization diagrams can be found in Section 2.3.

### 2.2.2 Single Aisle

For the S200 (178 capacity), three plugs were added to the base version with two in between the forward and aft wing, and one ahead of the forward wing. 8 frames being added: first class row with 12 seats and a 166 economy seating capacity.

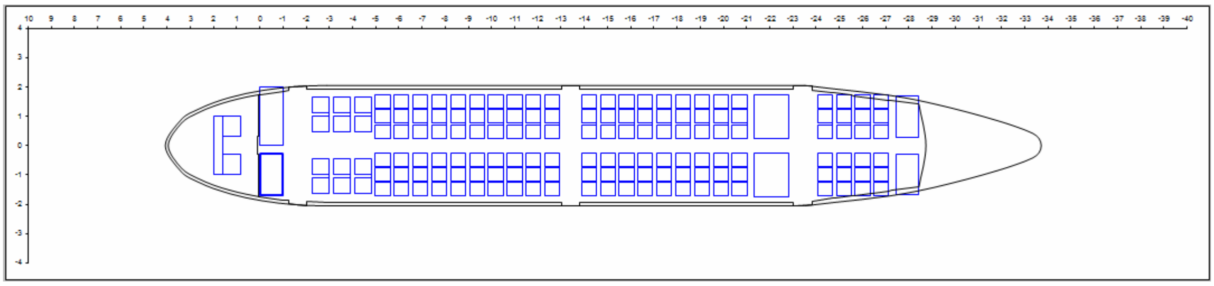


**Figure 4** Single Aisle S200- 126 seating capacity generated by PreSTo Cabin

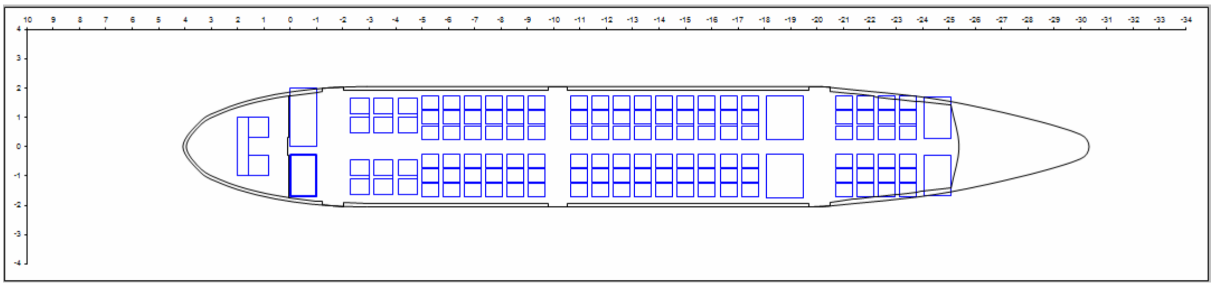


**Figure 5** Single Aisle Base version generated by PreSTo Cabin **[Schiktanz 2011]**

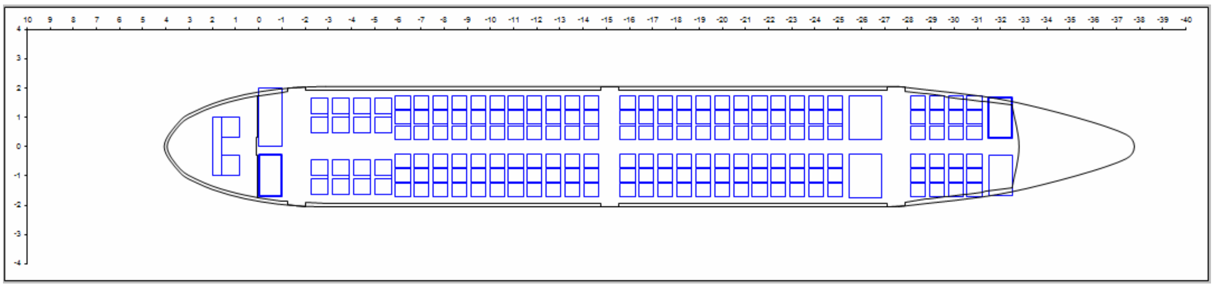


**Figure 6** Single Aisle S100 - 178 seating capacity generated by PreSTo Cabin

An update in V-tail sizing had been completed due to the very low $C_V$ values. This has been incorporated to all the family of slender aircraft. Figures 4, 5 and 6 above show the cabin layout generated with the help of PreSTo.

A frame system diagram has also been attached to show simplified, with detailed sections for the S200 aircraft. The same frame systems as that of the Airbus A320 have been used with some changes with respect to the box family. Final CAD drawings that are more accurate will be required once flight dynamic testing, wind tunnel testing commences. The diagram however forms the basis to future developers.

## 2.3 General Familiarization Diagrams

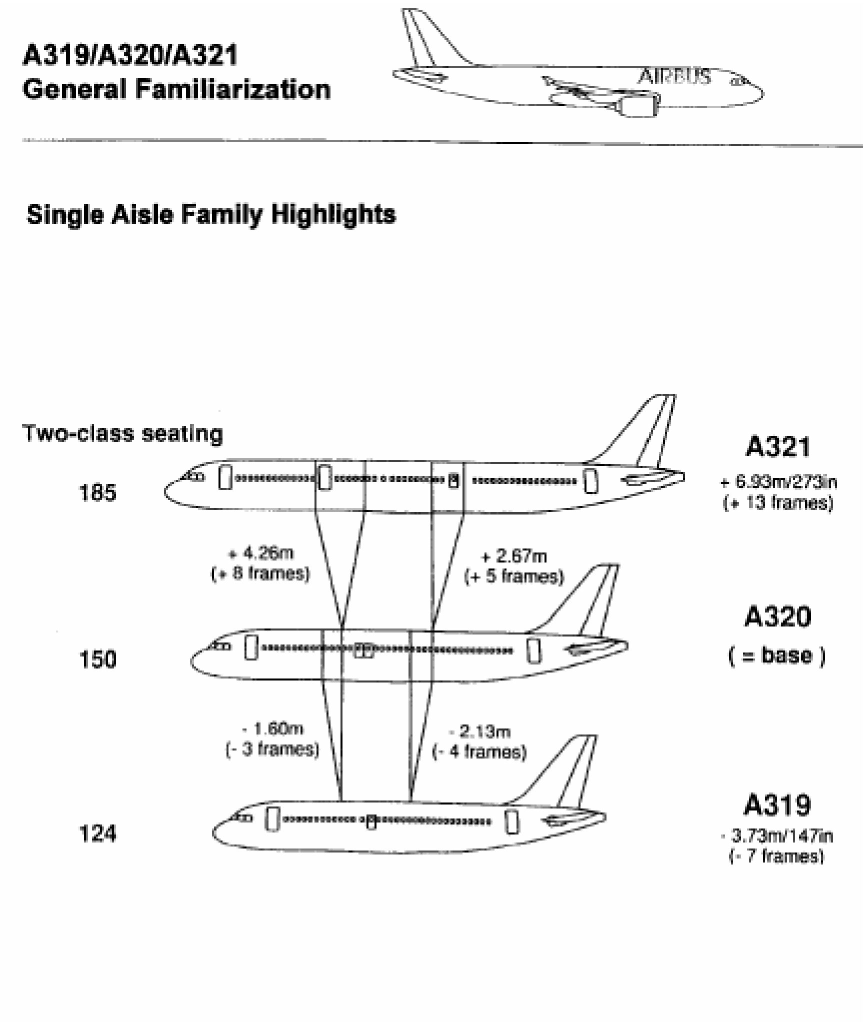
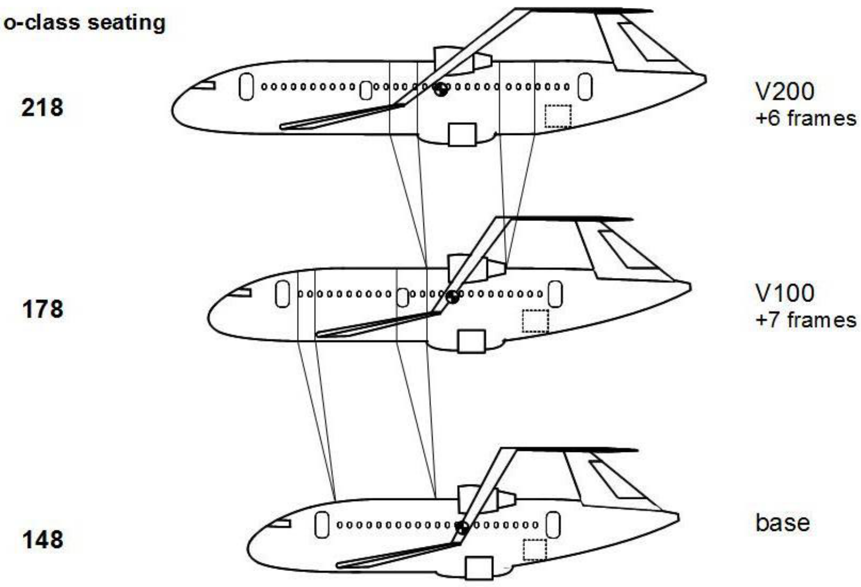


**Figure 7** Airbus General Familiarization diagram showing added plugs/frames- standard drawing when discussing family concept **[Airbus GF]**

***Box Wing***
***General Familiarization***

## Twin Aisle Family Highlights

**Two-class seating**



| | base | V100 | V200 |
|---|---|---|---|
| **Fuselage Length** | 33.1 m | 37.21 m | 41.28 m |
| **Underfloor Volume** | 34.17 $m^3$ | 38.42 $m^3$ | 42.62 $m^3$ |
| **Maximum take-off weight (MTOW)** | 74,328 kg | 85,008 kg | 96,845 kg |
| **Maximum zero-fuel weight (MZFW)** | 61,739 kg | 70,967 kg | 80,971 kg |
| **Operating Empty Weight (OEW)** | 41,793 kg | 47,967 kg | 54,251 kg |

| | base | V100 | V200 |
|---|---|---|---|
| **Longitudinal distance from AC1 to AC2 (l')** | 12.50 m | 15.50 m | 19.57 m |
| **Winglets Sweep** (at 25% chord) | 28.67° | 43.44° | 56.12° |

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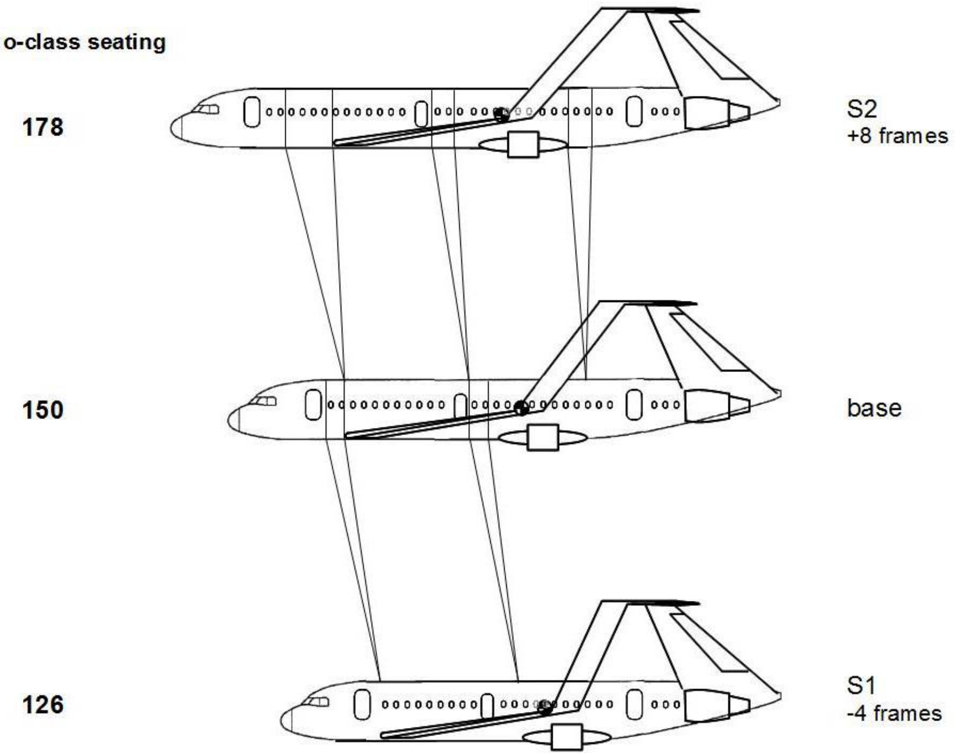
*2012-07-12*

***Box Wing***
***General Familiarization***

## Single Aisle Family Highlights

**Two-class seating**



| | base | S100 | S200 |
|---|---|---|---|
| **Fuselage Length** | 37.44 m | 34.09 m | 41.51 m |
| **Underfloor Volume** | 38.6 6m$^3$ | 35.20 m$^3$ | 42.86 m$^3$ |
| **Maximum take-off weight (MTOW)** | 76,887 kg | 69,742 kg | 86,042 kg |
| **Maximum zero-fuel weight (MZFW)** | 64,646 kg | 58,686 kg | 72,253 kg |
| **Operating Empty Weight (OEW)** | 44,524 kg | 40,918 kg | 49,649 kg |

| | base | S100 | S200 |
|---|---|---|---|
| **Longitudinal distance from AC1 to AC2 (l')** | 14 m | 12.9 m | 16 m |
| **Winglets Sweep** (at 25% chord) | 36.76° | 30.97° | 45.39° |

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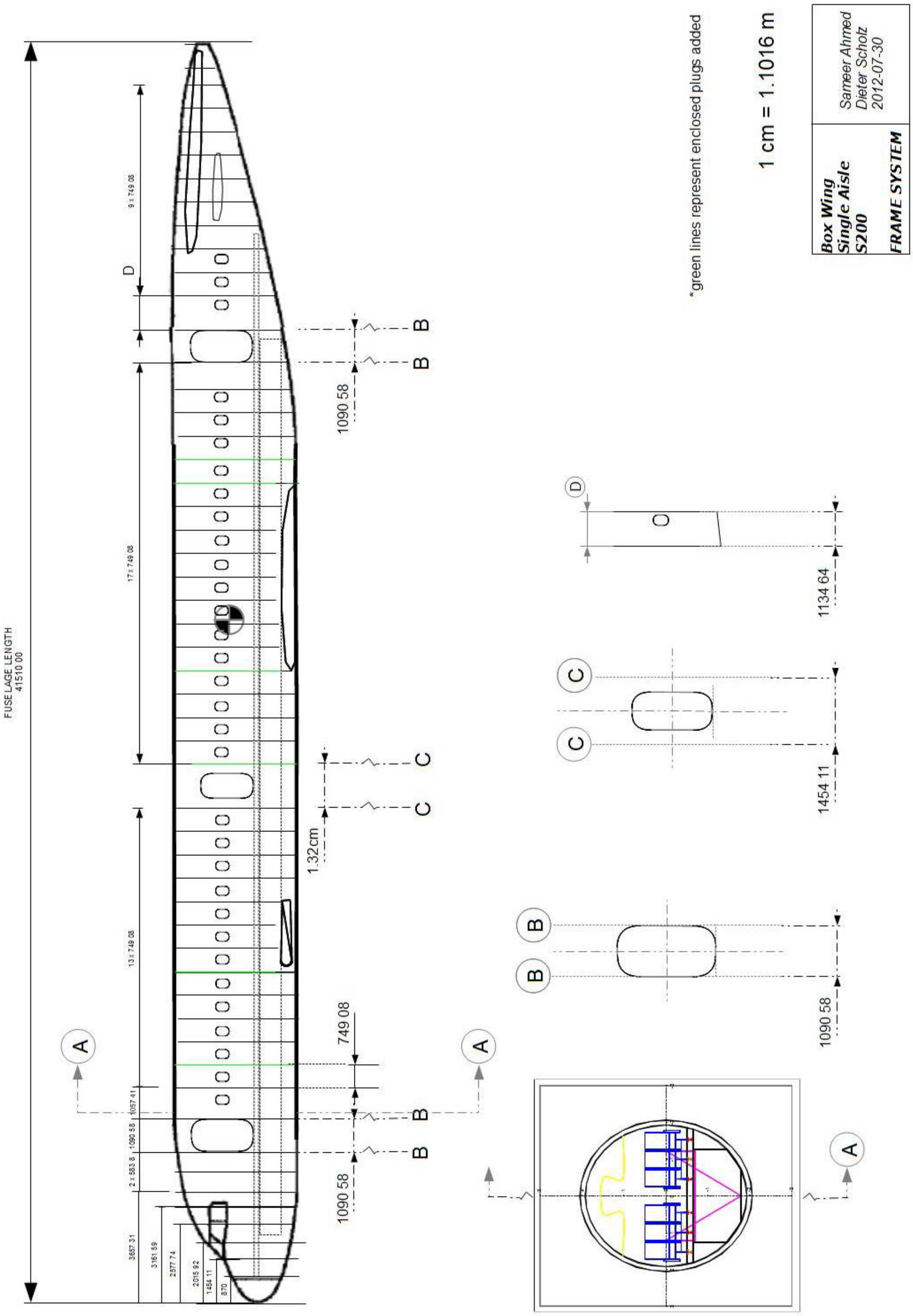
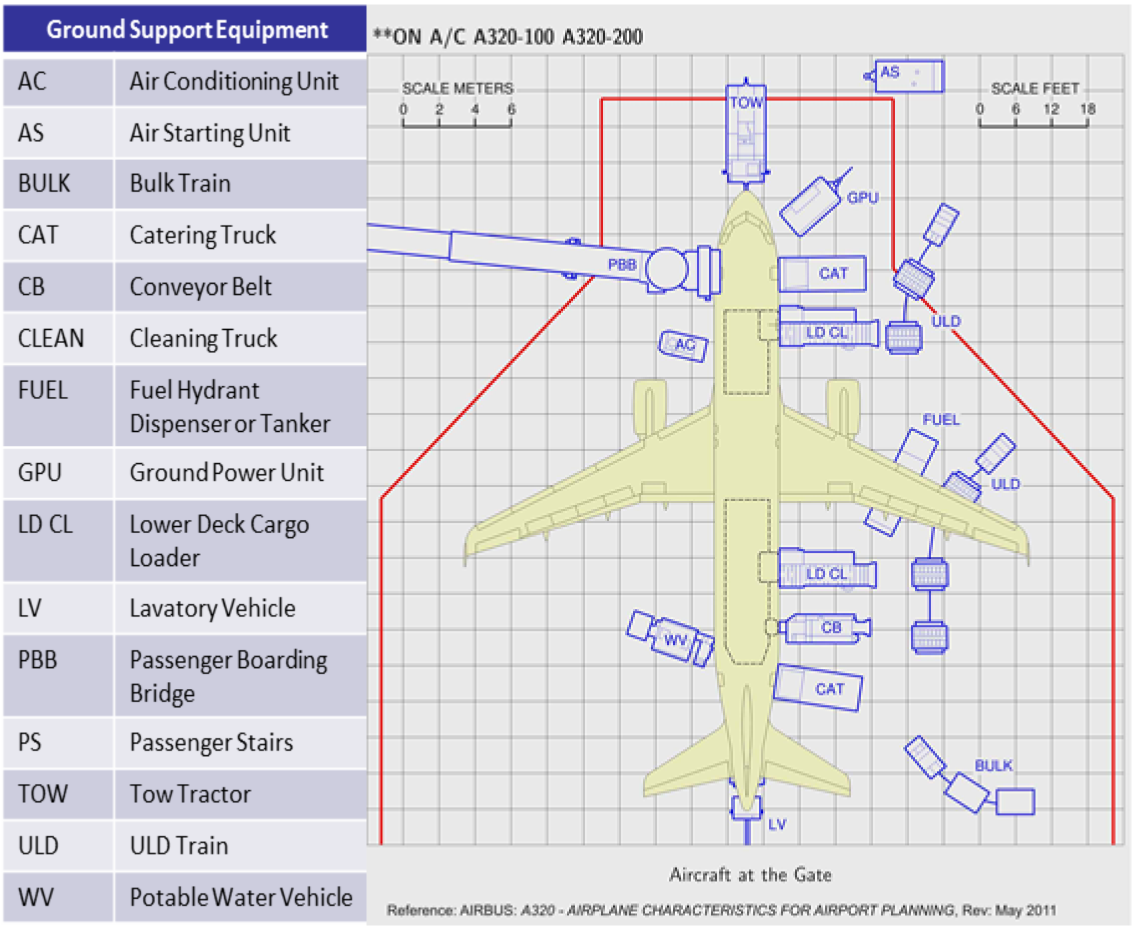

*green lines represent enclosed plugs added
1 cm = 1.1016 m
Box Wing
Single Aisle
S200
FRAME SYSTEM
Sameer Ahmed
Dieter Scholz
2012-07-30
FUSELAGE LENGTH
41510.00
9 x 749.08
17 x 749.08
13 x 749.08
D
1057.41
1090.58
2 x 583.8
3657.31
3161.59
2577.74
2015.92
1454.11
870
B
B
1090.58
C
C
1.32cm
749.08
1090.58
A
A
D
1134.64
C
C
1454.11
B
B
1090.58
A

## 2.4 Ground Handling

A trade study on the effect on ground handling on the proposed family has been conducted. Using the Airbus ground operating procedures as reference and their respective ramp layout diagrams, four new layouts are suggested.



| Ground Support Equipment | |
|---|---|
| AC | Air Conditioning Unit |
| AS | Air Starting Unit |
| BULK | Bulk Train |
| CAT | Catering Truck |
| CB | Conveyor Belt |
| CLEAN | Cleaning Truck |
| FUEL | Fuel Hydrant Dispenser or Tanker |
| GPU | Ground Power Unit |
| LD CL | Lower Deck Cargo Loader |
| LV | Lavatory Vehicle |
| PBB | Passenger Boarding Bridge |
| PS | Passenger Stairs |
| TOW | Tow Tractor |
| ULD | ULD Train |
| WV | Potable Water Vehicle |

**ON A/C A320-100 A320-200

Aircraft at the Gate

Reference: AIRBUS: *A320 - AIRPLANE CHARACTERISTICS FOR AIRPORT PLANNING*, Rev: May 2011

**Figure 11** Summary of Ground handling equipment on an Airbus 320 and the ramp layout

With the box wing aircraft, a continuous cargo compartment is suggested. However due to the positioning of the wings, the engines and the lower wing height (especially for the forward wings) some changes were required. Figure 11 shows the reference aircraft with its ground servicing arrangement.

| Ground Support Equipment | |
|---|---|
| AC | Air Conditioning Unit |
| AS | Air Starting Unit |
| BULK | Bulk Train |
| CAT | Catering Truck |
| CB | Conveyor Belt |
| CLEAN | Cleaning Truck |
| FUEL | Fuel Hydrant Dispenser or Tanker |
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| TOW | Tow Tractor |
| ULD | ULD Train |
| WV | Potable Water Vehicle |

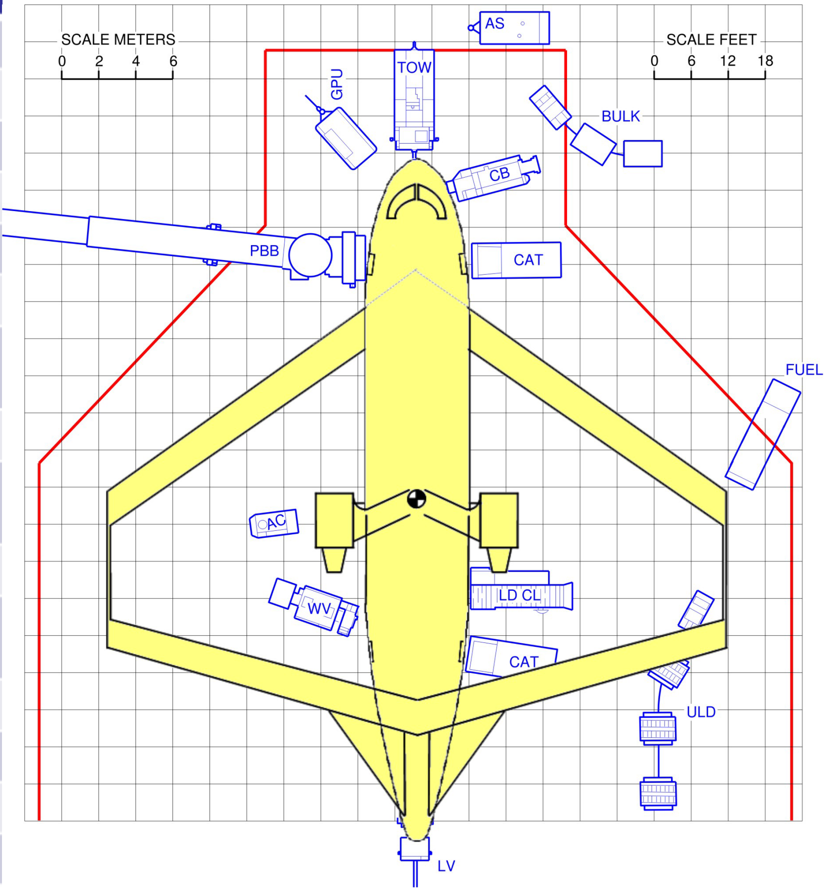


**Figure 12** Summary of Ground handling equipment on V100 and the ramp layout

Industry procedures today follow loading and unloading of cargo using a critical path with the use of one Lower deck cargo loader (LDCL). In regards to the continuous cargo compartment, two LDCL could decrease the turnaround however; it is not possible to have them simultaneously due to the layout of the aircraft. The single aisle S200 is an exception though, and takes advantage of two LDCL (Figure 14). Conveyor belt (CB) which is used to load the bulk compartment as well as luggage too big for the cabin, has been proposed to be near the nose wheel. Position of Ground Power Unit is changed for twin aisle due to the location of CB, simply laid out at the port side. In regards to the slender family, CB is incorporated with the cargo loader door and hence the same vehicle will be used for both. The two separate LDCL doors should make up for the time lost during bulk loading.

| Ground Support Equipment | |
|---|---|
| AC | Air Conditioning Unit |
| AS | Air Starting Unit |
| BULK | Bulk Train |
| CAT | Catering Truck |
| CB | Conveyor Belt |
| CLEAN | Cleaning Truck |
| FUEL | Fuel Hydrant Dispenser or Tanker |
| GPU | Ground Power Unit |
| LD CL | Lower Deck Cargo Loader |
| LV | Lavatory Vehicle |
| PBB | Passenger Boarding Bridge |
| PS | Passenger Stairs |
| TOW | Tow Tractor |
| ULD | ULD Train |
| WV | Potable Water Vehicle |

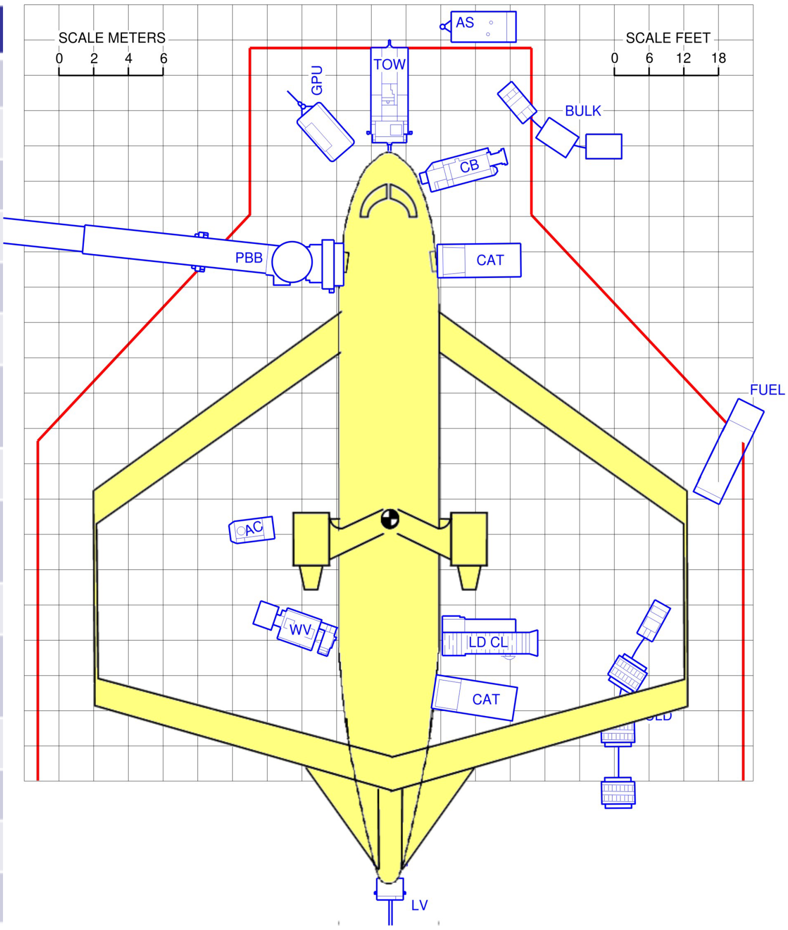
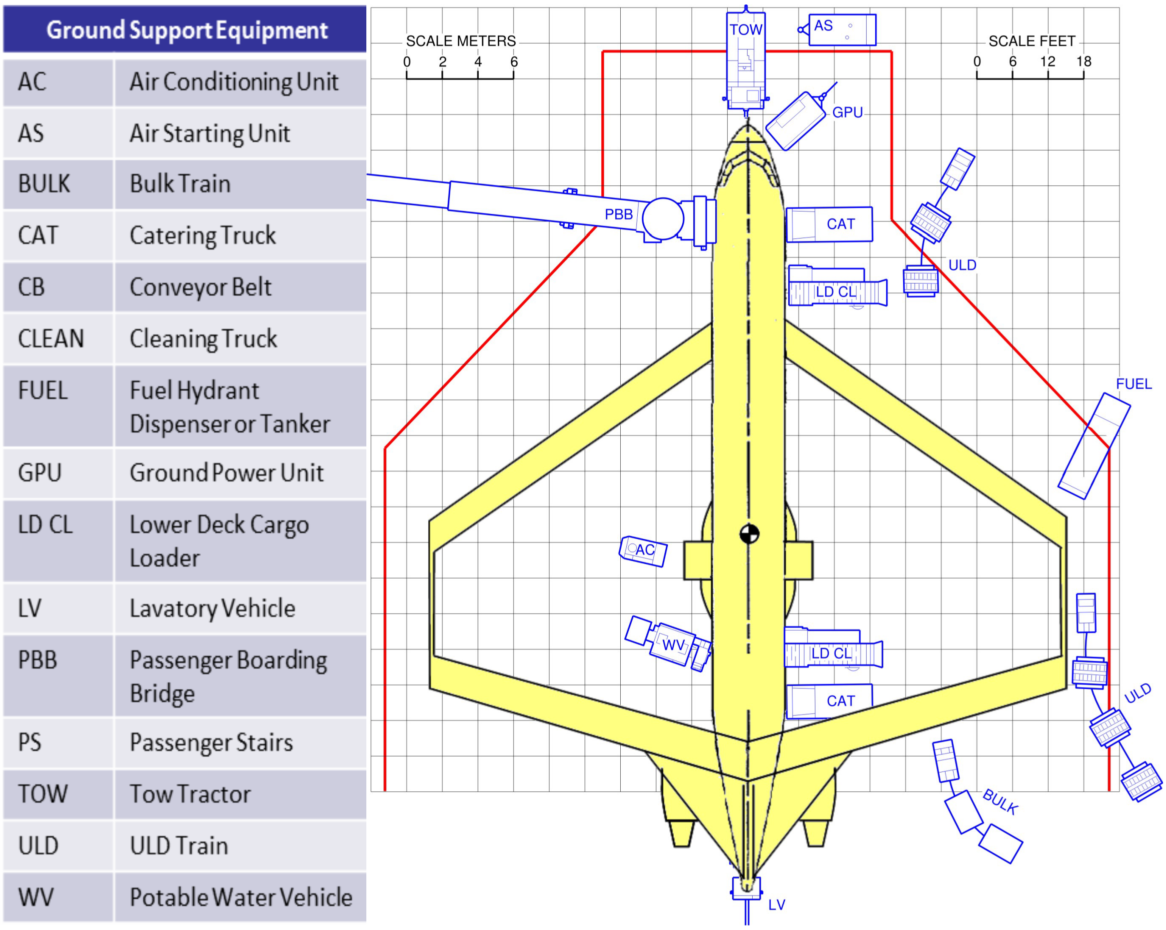


**Figure 13** Summary of Ground handling equipment on V200 and the ramp layout



| Ground Support Equipment | |
|---|---|
| AC | Air Conditioning Unit |
| AS | Air Starting Unit |
| BULK | Bulk Train |
| CAT | Catering Truck |
| CB | Conveyor Belt |
| CLEAN | Cleaning Truck |
| FUEL | Fuel Hydrant Dispenser or Tanker |
| GPU | Ground Power Unit |
| LD CL | Lower Deck Cargo Loader |
| LV | Lavatory Vehicle |
| PBB | Passenger Boarding Bridge |
| PS | Passenger Stairs |
| TOW | Tow Tractor |
| ULD | ULD Train |
| WV | Potable Water Vehicle |

**Figure 14** Summary of Ground handling equipment on S200 and the ramp layout

| Ground Support Equipment | |
|---|---|
| AC | Air Conditioning Unit |
| AS | Air Starting Unit |
| BULK | Bulk Train |
| CAT | Catering Truck |
| CB | Conveyor Belt |
| CLEAN | Cleaning Truck |
| FUEL | Fuel Hydrant Dispenser or Tanker |
| GPU | Ground Power Unit |
| LD CL | Lower Deck Cargo Loader |
| LV | Lavatory Vehicle |
| PBB | Passenger Boarding Bridge |
| PS | Passenger Stairs |
| TOW | Tow Tractor |
| ULD | ULD Train |
| WV | Potable Water Vehicle |

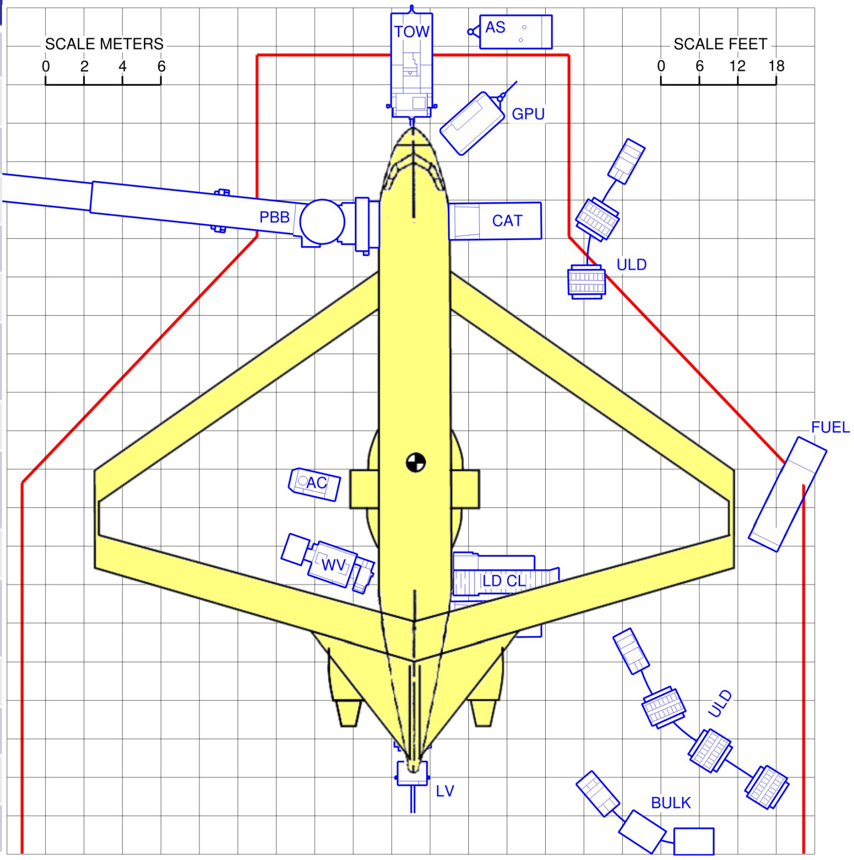


**Figure 15** Summary of Ground handling equipment on S200 and the ramp layout

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