FINAL ENGINEERING DEFINITION REPORT

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SUMMARY

The design objective behind oVal landing gear is to achieve minimum landing gear height to benefit from high utilisation, minimum weight, reduced life cycle cost, and satisfying regulatory and safety requirements. The design process is iterative and highly dependent to airframe design, weight and balance, and propulsion specialists. The MTOW initial and final estimates were 155,000kg and 175,060kg respectively. A single NLG bogie with tyres in tandem and two MLG bogie with 4 tyres arranged in twin tandem were selected as the landing gear configuration.

Landing gear tyres were sized to allow easy of steering and maximum stability of the aircraft. Moreover, criterion looked into for tyres and bogie geometry is to achieve desired ACN Flexible B of 51.3. Wing-mounted MLG was chosen after considering structural, balance, and aerodynamic factors. The integration solution was to place MLG attachment points on the wings and stow them into the wing belly.

	Main landing gear	Nose landing gear
No of wheels per strut	4	2
Tyres	46 x 18 x R20	40 x 14.5 x R19
Bogie pitch	1.52m	
Bogie track	0.93m	
Type of shock absorber	Oleo-pneumatic	Oleo-pneumatic
Rake angle	7°	
Wheel base	28.4m	
Wheel track	8.6m	
Height of landing gear from ground to bottom of fuselage	1.86m	
ACN flexible B	51.3	

1. CONTENTS

NOMENCLATURE

MLG	Main landing gear
NLG	Nose landing gear
LG	Landing gear
MTOW	Maximum take-off weight
MLW	Maximum landing weight
CG	Centre of gravity
ACN	Aircraft classification number
ICAO	International Civil Aviation Organisation
FAA	Federal Aviation Administration
DOC	Direct operating cost
CS	Certification Specification
EMA	Electro-mechanical actuator
EIS	Entry into service
RTO	Rejected take-off

2. INTRODUCTION

2.1. Design Philosophy

The design target behind oVal landing gear is to achieve minimum landing gear height to achieve high utilisation, minimum weight, reduced life cycle cost, and satisfying regulatory and safety requirements. The design process is iterative and highly dependent to airframe design, weight and balance, and propulsion specialists. Once the initial MTOW has been established, it is possible to determine suitable arrangement. It is also important to account for stretch variants into the initial design process. Initial configuration was guesstimated with comparison from aircrafts in service of similar MTOW and studied using trade-off analysis (***see Appendix A***). The MTOW initial and final estimates were 155,000kg and 175,060kg respectively. In early iteration, single NLG bogie with tyres in tandem and two MLG bogie with 4 tyres arranged in twin tandem were selected. The landing gears were also designed to retract into the aircraft to reduce drag and able to extend and locked in through free-fall.

In the PDR stage, landing gear tyres were sized by achieving a target 2.5-15% loading on NLG and 85-97.5% loading on MLG. This is to allow easy of steering and maximum stability of the aircraft. Another criterion looked into at this design stage is achieving desired ACN Flexible B. This criterion also drives the loading distribution and tyre selection. The longitudinal positions of the landing gears were then determined from loading distributions and tail-scrape conditions. The lateral stability of the aircraft was then considered to determine the wheel track.

At this stage, an engineering decision was made to determine the MLG attachment through combined qualitative trade-off analysis (***see Appendix B***) and engineering judgement. As a result, wing-mounted MLG was chosen as initial choice. In later stage, this is refined after considering structural, balance, and aerodynamic factors. The integration solution was discussed and a consensus was achieved to place MLG attachment points on the wings and stow them into the wing belly. Unlike fuselage fairings mounted MLG, it does not result in higher aerodynamic and weight penalties. In post-PDR stage, methods were refined and more iterations took place after series of changes in overall aircraft design.

3. FINAL DESIGN PROCESS

3.1. Longitudinal Position

The key driver of the landing gears was determined by position of CG to meet controllability and stability of the aircraft requirements. Due to rear engine mounted configuration, the engine clearance or aircraft nose collapse was not the key driver to longitudinal position of landing gears. The CG position were located towards aft of the aircraft and has a narrow range of 31.4m to 33.6m in the x-direction from nose. This posed an engineering limitations to the placement of the landing gears. The position of the landing gears was then satisfied in ***Table 1*** and is illustrated in ***Figure 2***. Key details of longitudinal position of landing gear is tabulated in ***Table 3***.

Table 1: Longitudinal position of landing gear requirements

Requirements	Checks
MLG must be placed at rearmost CG to provide nose down restoring moment in an event of tail strike	✓
MLG must carry 97.5-85% of MTOW for stability and balance to avoid tip down moment	✓
NLG must carry 2.5-15% of MTOW for ease of steering and rotation during take-off	✓
Tip back angle must be greater than 15° to prevent aircraft from tipping into its tail	✓
There must be enough clearance for take-off rotation to prevent tail-scrape damage	✓

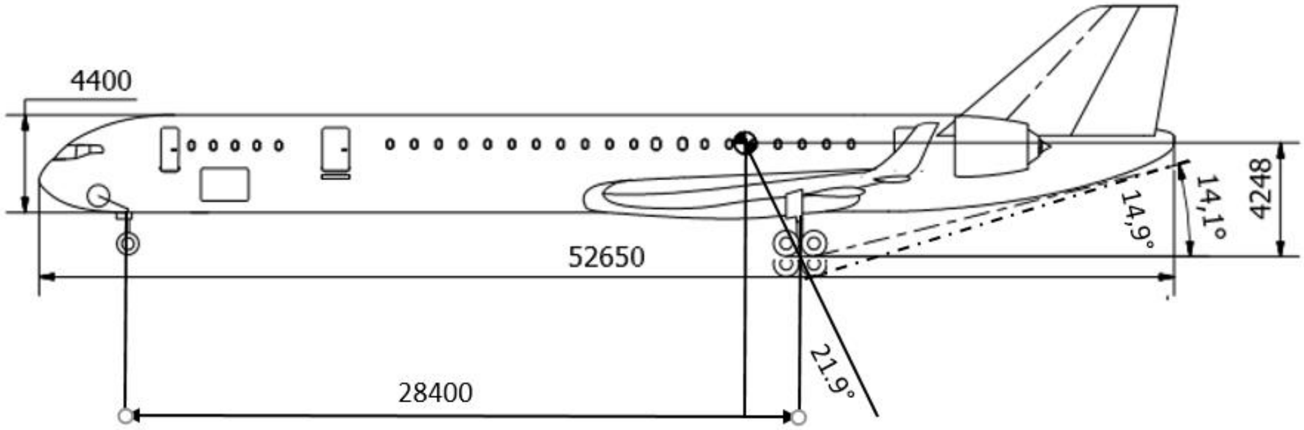


Figure 2: GA representation of tip back angle and take-off rotation angle

Table 3: Key details of longitudinal position of landing gear

Key Feature	Value
Wheel base	28.4m
MLG x-position from aircraft nose	32.8m
NLG x-position from aircraft nose	4.4m
Take-off rotation angle, γ	14.9°
Tip-back angle, ß	21.9°

3.2. Landing Gear Load

The CG position drives the load distribution between MLG and NLG. The CG positions and range were calculated and provided by Weight and Balance specialist based on fuel load distribution and payload changes. The MLG and NLG loading factor can be determined based on moment equilibrium under static condition as shown in ***Table 5*** and illustrated in ***Figure 4***.

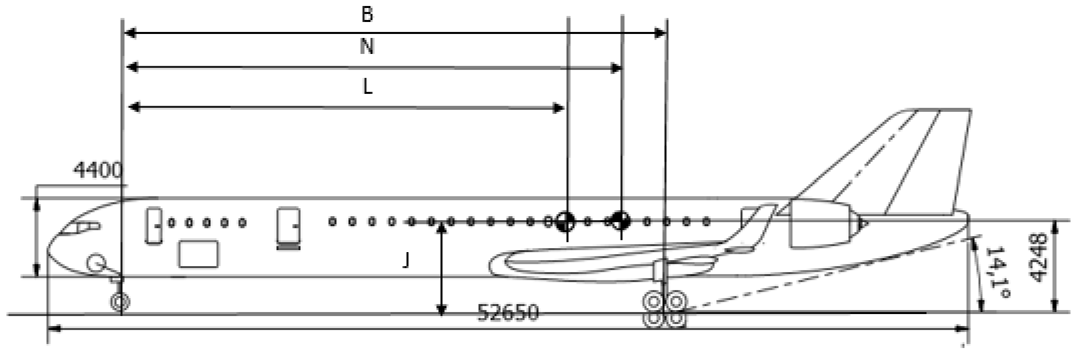


Figure 4: Static load diagram

Table 5: Static 1g load and moment equilibrium formula used for loading distribution

	Formula	% MTOW loading
Min static NLG load	W*(B-N)/B	3.6
Max static NLG load	W*(B-L)/B	10.6
Min static MLG load	W*N/B	89.4
Max static MLG load	W*L/B	96.4

3.3. Lateral Position

The lateral stability and certain airport regulations drove the lateral position of the landing gears. The lateral position ensures that the aircraft does not roll over during cross-wind conditions or during performed turns. The lateral position of landing gears gives out the dimension of wheel track. Moreover, this position was also related to the height of the aircraft. Based on ICAO Code D, the MLG outboard wheel span should be greater than or equal to 9m and less than 14m. The wheel track was designed to comply as closely as possible to the regulatory requirements and achieve short landing gear. The lateral position of the landing gears was then validated by satisfying roll angle clearance and turnover angle.

In the initial stage, the wheel track was set as 9m. After few refined iterations and identified tyre size and bogie dimensions, the finalised wheel track chosen was 7.2m with an outboard span of 8.6m. The required turnover angle should not exceed 63° for land-based aircraft. oVal landing gear succeeded in fulfilling this criterion as depicted in ***Table 6*** (***refer to Appendix C for figure***).

The roll-over angle has to be greater than 5° to prevent engine touchdown. However, due to its rear-mounted engine position, it is more sensible to account for wing tip scrape against ground during crosswind taxiing or landing. This is determined from landing gear height, wheel track, and wing tip position. As a result, the roll-over angle achieved was 14° as shown in ***figure 7***

Table 6: Formula used to calculate turnover angle

	Formula	Values
Y	D*sinα	4.11m
Turnover angle, ϴ	ATan(E/Y)	46.2°

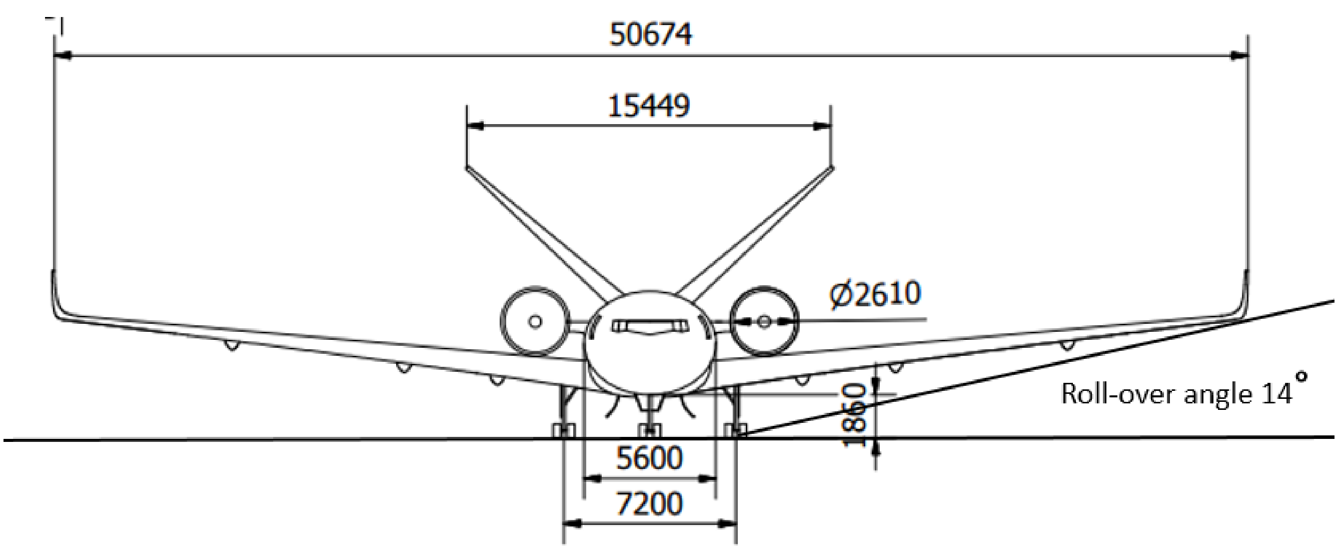


Image 7: GA representation of roll-over angle

3.4. Steering and Taxiing

The key driver for steering and taxiing is the compatibility with existing airports. ICAO code D required safety margin or turning circle clearance of at least 4.5m between both MLG and NLG outboard sides to the end of runaway during 180° turn. Current operating aircrafts operates at about 55°-70° steering angle. Based on this, the initial steering angle was guesstimated to be at 60°. However, as seen in ***Table 8*** the turning circle clearance was well below requirement by ICAO code D.

Further iterations were carried out while taking account of the slip angle of 5° to determine the ranges of steering angle which resulted in acceptable turning circle clearance. The ranges were identified to be at least 70° for this aircraft. The steering angle chosen was 75° to achieve enough clearance to comply with ICAO code D. This was not overdesigned as greater steering angle leads toward faster wear and tear. This would increase maintenance cost and DOC.

Table 8: Turning circle clearance and total turn width

Steering Angle, °	Actual Steering Angle, °	Turn width (m)	Turning circle clearance (m)
65	60	44.7	0.3
70	65	37.7	7.3
75	70	34.8	10.1
80	75	32.3	12.7
85	80	30.0	15.0

3.5. Tyre Selection

Once the static 1g loading on each tyres were established, tyre selections can be performed. As required by CS 25.733, a safety margin of 1.07 was accounted to static loading calculations. The MLG tyres were sized based on static loading on MLG. It is also important to ensure that the static rated load of chosen tyre is greater than single tyre operating load. To comply with most airport, chosen static load tyre rating should have rated pressure lower than code X airport pressure limit of 254psi.

This would affect the ACN and should not result in ACN greater than 60. Radial tyres were chosen as the MLG and NLG tyres as opposed to bias tyres. This is due to its lower weight and high durability which gives out lower ACN. MLG tyres were chosen from Goodyear tyre data [5] and shown in ***Table 9***.

Table 9: Tyre dimension and candidate tyres for MLG

Tyre size: 46 x 18 x R20		Tyre size: 49 x 18 x R22	
Single tyre operating load	22,236 kg or 51,143 lbs	**Single tyre operating load**	22,236 kg or 51,143 lbs
Static rated load	51, 900 lbs	**Static rated load**	52,235 lbs
Rated pressure	205 psi	**Rated pressure**	219 psi
Diameter	46 inch	**Diameter**	49 inch
Width	18 inch	**Width**	18 inch
Rim diameter	20 inch	**Rim diameter**	22 inch

Tyre size 46 x 18 x R20 was chosen as it gives adequate rated load and has smaller dimensions. It is favourable to use tyres of similar static rated load which gives smaller dimensions to optimise stowage space. However, it is imperative to ensure that the static rated load fulfils critical dynamic load as shown later. The operating loaded pressure is then determined as shown in below formula. This is to ensure the tyres were operating within code X airport tyre pressure limit of 15 bar.

Operating loaded pressure *= 1.04*rated pressure*single tyre operating load/static load =* ***13.79 bar***

NLG tyres were sized based on maximum braking load which was calculated at sink rate of 10ft/sec. The braking load calculation made is shown below.

Braking load = V_s*H*W/(g*B) = ***8,356 kg*** *or* ***19,217 lbs***
where V_s *= sink speed, H = height of CG from ground, B = wheel base*

Single tyre operating load *= (max static nose load + braking load)/2 =* ***13,847 kg*** or ***31,847 lbs***

Table 10: Tyre dimension and candidate tyres for NLG

Tyre size: 40 x 15 x R16		Tyre size: 40 x 14.5 x R19	
Single tyre operating load	13,847 kg or 31,847 lbs	**Single tyre operating load**	13,847 kg or 31,847 lbs
Static rated load	39,500 lbs	**Static rated load**	33,200 lbs
Rated pressure	195 psi	**Rated pressure**	200 psi
Diameter	40 inch	**Diameter**	40 inch
Width	15 inch	**Width**	14.5 inch
Rim diameter	16 inch	**Rim diameter**	19 inch

The tyre 40 x 14.5 x R19 was chosen as it provides optimum static rated load after accounting for braking load. This is to ensure lighter landing gear and requiring smaller stowage space. The operating loaded pressure is then determined as shown in below formula. This is to ensure the tyres were operating within code X airport tyre pressure limit of 15 bar.

Operating loaded pressure *= 1.04*rated pressure*single tyre operating load/static load =* ***13.22 bar***

Table 11: Critical load cases for MLG

CS 25.493 Braked roll		CS 25.495 0.5g turning case		CS 25.491 Take off bump, F_Z
Vertical load per wheel, F_z	Braked roll per wheel, F_Z	Inner wheel	Outer wheel	
43,332 lbs	34,666 lbs	31,826 lbs	10,656 lbs	46,110 lbs

Chosen tyres were validated with several critical dynamic loading cases as shown in ***Table 11*** to ensure its reliability. It was checked against chosen tyre's static rated load ***(see Appendix D for methods)***. As the MLG static rated load of 51,900 lbs was above than any of the critical load cases, it was locked as final choice of MLG tyre.

3.6. Pavement Loading

The ACN represents load exerted on runaway pavement and is a function of MTOW, bogie geometry, landing gear design and tyre pressure. The pavement loading applied from MLG bogies should not exceed ACN flexible B 60. The ACN will decrease with an increase in wheel axle track and pitch. However, this is met with structural constraints in terms of stowage room for our aircraft. To calculate the ACN, the geometry of the MLG bogie of Boeing 767-300 ER were modified as starting estimate due to its similarities in MTOW using COMFAA 3.0

software as shown in ***Figure 12***. The wheel axle track and pitch of the MLG bogie underwent few changes in order to integrate the landing gears in the wing belly. The landing gear footprint obtained is illustrated in ***Figure 13***.

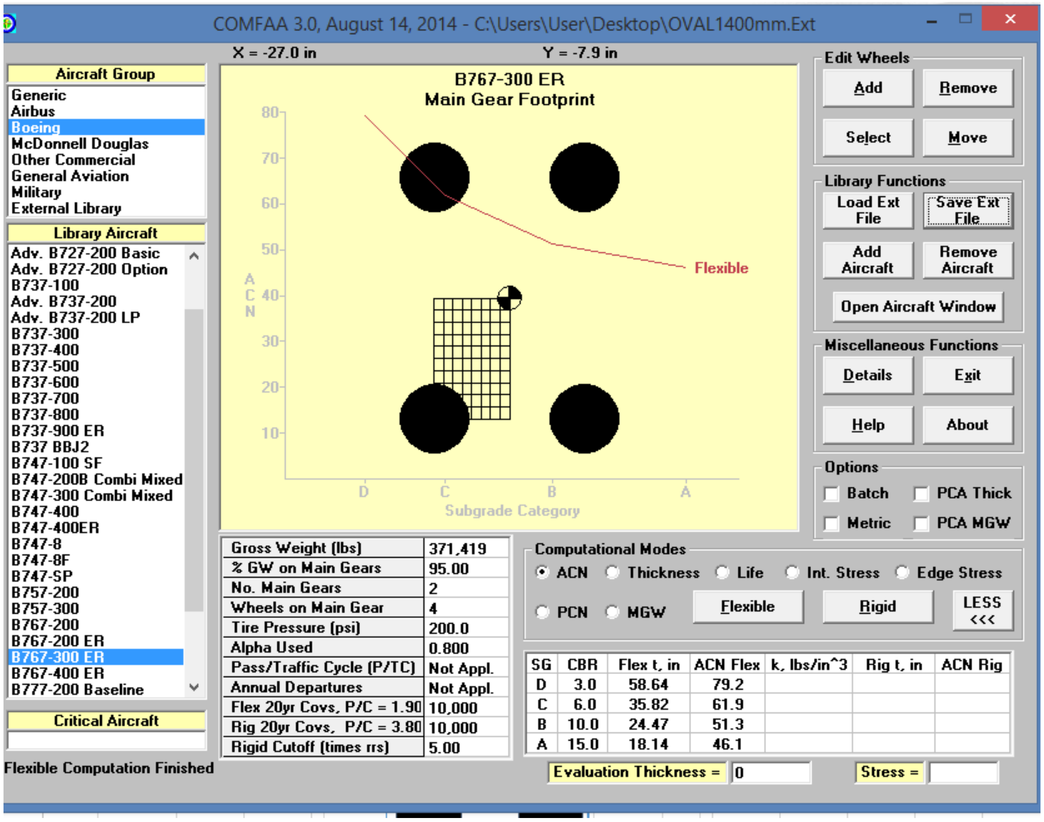


Figure 12: COMFAA 3.0 software used to calculate ACN

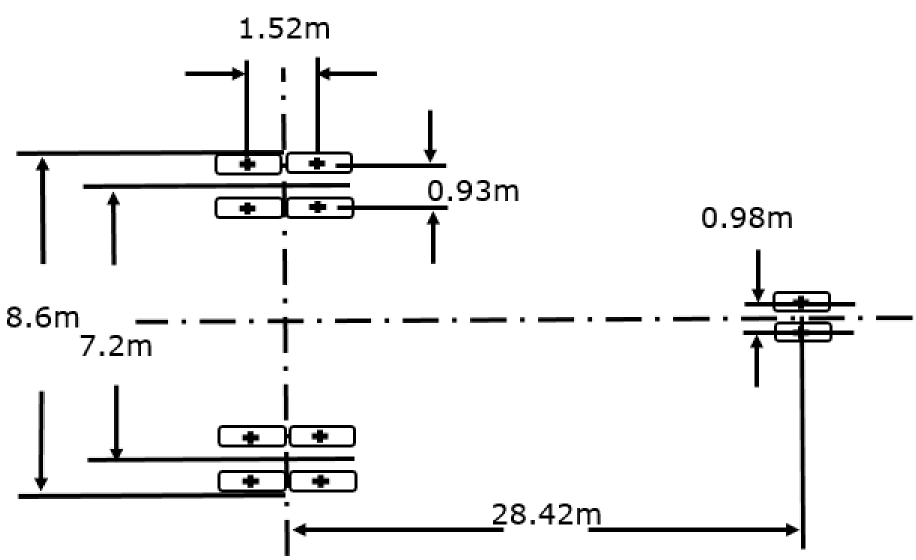


Figure 13: Landing gear footprint

3.7. Shock Absorber Design and Landing Gear Height

A shock absorber design should be able to absorb and dissipate kinetic energy upon impact. In the early design stage, shock absorber design is a function of load factor, stroke, shock absorber efficiency, and sinking speed. In order to design a shock absorber, the vertical axle travel or stroke length has to be determined through equating tyre and strut energy with kinetic and potential energy. The size of oleo which includes stroke length, sliding tube area, internal diameter of main fitting, and length of piston were also determined as shown in ***Table 15***. An extra inch was added into the stroke length calculation for redundancy. These were obtained using the following equation:

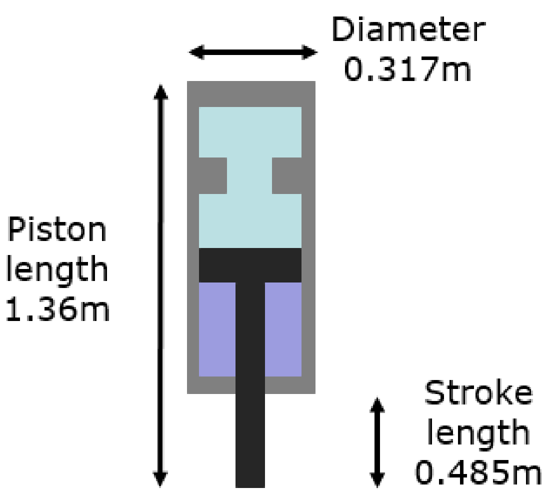


Image 14: Oleo piston schematic

$$S_s = \frac{\frac{V^2}{2\lambda g} - \eta_T S_T}{\eta_s}, A = \frac{F_s}{P_g}, D_{inner} = \sqrt{\frac{4F_s}{P_g \pi}}, L_{piston} = S_s + 2.75 D_{inner}$$

Where S_s = stroke length, V = vertical descent velocity, λ = reaction factor, η_T =tyre efficiency, η_s =shock absorber efficiency

Table 15: Shock absorber design key parameters

	Type of shock absorber	Stroke length, m	Sliding tube area, m²	Internal diameter of main fitting, m	Length of piston, m	Tyre deflection, m
MLG	Oleo-pneumatic single acting shock absorber	0.485	0.079	0.317	1.36	0.429
NLG	Oleo-pneumatic single acting shock absorber		0.021	0.162	0.90	0.346

The landing gear height H_{LG} was governed by aircraft ground clearance which was determined by the position and diameter of the engine. The engine ground clearance has to be at least greater than 0.23 of fan diameter of the engine. However, due to oVal's rear mounted engine this does not apply as design driver for landing gear height which proved its advantage over other engine configuration which allowed shorter landing gear design as shown in ***Table 16.***

Table 16: Landing gear height

MLG extended height	MLG and NLG height from bottom of fuselage
3.23m	**1.87m**

3.8. Brakes

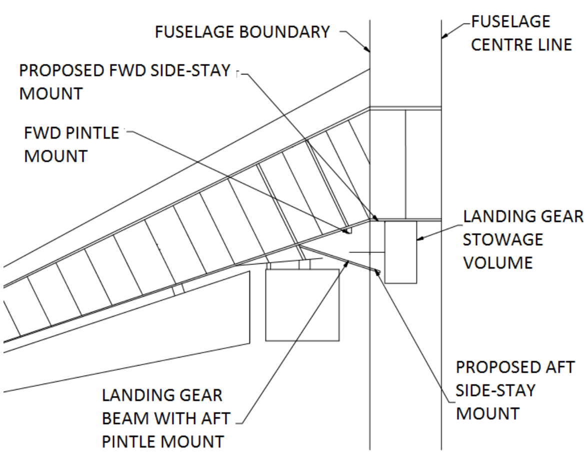
An electro-mechanical actuated brake system will be used instead of hydraulic powered brakes. This was chosen for lower maintenance which drives lower life cycle cost, better weight savings, and improved reliability as seen in A330-300 [6]. The heat sink material used for the brake were carbon as it has higher specific heat, thermal conductivity, thermal expansion, thermal resistance and higher temperature limit than steel. The brakes were sized based on FAA requirements for 100 stops at average of 10 ft/sec^2 deceleration at design landing weight, 5 stops at average of 10 ft/sec^2 deceleration at maximum landing weight and 1 stop at average of 6 ft/sec^2 deceleration at rejected take-off as shown in below ***Table 17***. The carbon brakes were fitted with anti-skid system auto brake system to prevent skidding on wet or icy pavements and to allow braking operations during aircraft landing.

Table 17: Brake sizing for critical conditions set by FAA

Brake assembly weight for rejected take-off	Brake assembly weight for 5 stops	Brake assembly weight for 100 stops	Heat sink volume
90 lbs	110 lbs	120 lbs	278.8 inch^3

3.9. Kinematics and Stowage

The landing gear extension and retraction system (LGERS) designed should be able to perform controlled landing gear extension and retraction while closing and opening the stowage door during take-off, landing, and flight. The LGERS incorporated two inward retracting wing mounted MLG which will be stowed in wing belly and a single forward retracting NLG which will be stowed in the fuselage. The MLG were installed at 7° rake angle and uses double side-stay which allows landing gear to extend by free falling due to gravity and locked in position in case of emergency.



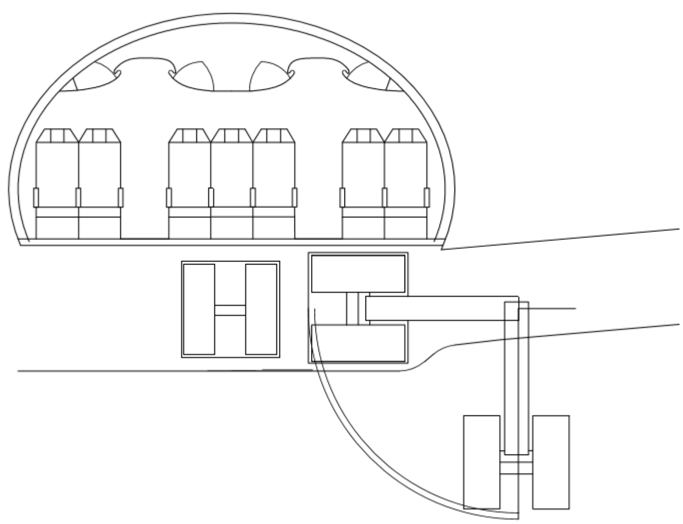


Image 18 (left): Attachment point of the double side-stay mount, pintle mount, and its landing gear stowage
Image 19 (right): Simplified kinematics of inward retracting wing mounted MLG and the stowage bay accounting for 80mm clearance

3.10. Materials Selection and Manufacturing

Materials for landing gear were carefully selected with intention to reduce DOC through higher reliability and lower maintenance cost. oVal concept will utilise advanced materials which has been used by current and previous aircrafts to achieve weight savings.

Gear Beam

The gear beam should be able to operate in extreme cyclic loading as it takes in load and distributes it from the landing gear to the rear spar of the wing box. As shown in ***Image 18***, a long gear beam was designed into the wing box to fit the landing gear. Hence, it was important to choose a material which has high strength and has high crack resistance in extreme cyclic loading. The gear beam was designed to be made of titanium alloy to fulfil the loading requirements.

Braces

The side braces should be able to withstand the loading of landing gear during extension and retraction and locked in place. It must also have high stiffness as it will experience compressive and tensile force during operation. One of failure mode considered behind the material choice was buckling mode failure. Hence, titanium will be used as braces material to prevent buckling mode failure.

Shock Strut

The shock strut should be able to support weight and have high resistance to corrosion as it is exposed to environment readily during off and on flight operation. The material chosen has to be of high strength and high corrosion resistance. The shock strut here was designed to be made of titanium alloy as to provide the required characteristics.

Manufacturing Process

Majority of the landing gear components were made of materials commonly used in current aircrafts. There were no novel materials used for the landing gear design and should not pose unusual manufacturing risks. This would keep manufacturing cost low as it does not require any development and risk of accreditation.

3.11. Weight Estimates

A typical landing gear weighs between 3-5% of MTOW and sized based on stretch version of the aircraft. Two different methods were employed to estimate using empirical approach based on landing gear characteristics by Currey and Torenbeek [3].

Currey's Method

Currey's method sizes landing gear weight based on landing gear characteristics which includes landing gear strut length, rough field and high flotation capability [2]. In this case, the landing gear was considered short landing gear with high rough field and high flotation capability. It was calculated using the following formula:

$$W_{LG}=0.046 x K_{LG} x W_L = \mathbf{7{,}404\ kg} \text{ or } \mathbf{16{,}344\ lbs}$$

Torenbeek's Method

Torenbeek's method sizes landing gear weight as a function of MTOW. It was calculated using the following equation:

$$W_{MLG}=40+0.16 x MTOW^{3/4}+0.019 x MTOW+1.5x10^{-5} x MTOW^{3/2}=\mathbf{6{,}096\ kg} \text{ or } \mathbf{13{,}456\ lbs}$$

$$W_{NLG}=20+0.1 x MTOW^{3/4}+2x10^{-6} x MTOW^{3/2}= \mathbf{928\ kg} \text{ or } \mathbf{2{,}049\ lbs}$$

$$W_{LG}= \mathbf{7{,}024kg} \text{ or } \mathbf{15{,}505\ lbs}$$

The approach towards landing gear design was chosen to be conservative for redundancy. Moreover, it was also important to acknowledge weight contribution of gear beam. Both of the methods were used to validate each methods and resulted similar estimates. As a result, the estimated landing gear weight was 16,344 lbs or 7,404 kg (***see Table 20***) which accounts for 4.23% of MTOW which is within the standard weight range.

Table 20: Top down landing gear weight breakdown based on Currey's weight estimation

Landing gear weight breakdown			
Main landing gear		**Nose landing gear**	
Rolling stock (29%)	4,739 lbs	**Rolling stock (4%)**	2,451 lbs
Wheel (7%)	1,144 lbs	Wheel (1.5%)	245 lbs
Tyre (10%)	1,634 lbs	Tyre (2.5%)	408 lbs
Brake (12%)	1,961 lbs	Brake (0%)	0 lbs
Misc (0%)	0 lbs	Misc (0%)	0 lbs
Structure (48%)	7,845 lbs	**Structure (7%)**	1,114 lbs
Shock strut (30%)	4,903 lbs	**Shock strut (4%)**	653 lbs
Braces (12%)	1,961 lbs	Braces (1%)	163 lbs
Fittings (5%)	817 lbs	Fittings (1%)	163 lbs
Misc (1%)	163 lbs	Misc (1%)	163 lbs
Control (8%)	1,307 lbs	Control (4%)	653 lbs
Total MLG weight (85%)	13,892 lbs	**Total NLG weight (15%)**	2,451 lbs
Total landing gear weight		**16,344 lbs or 7,404 kg**	

4. TECHNOLOGY MATURITY AND RISKS LEVEL

oVal concept landing gear components were made of technology commonly used by current civil aircrafts. Since there was no rear engine mounted aircraft of similar size to oVal, there were no definite nor direct comparison that can be made when designing the landing gear. Hence, validation risk was identified as it was difficult to establish whether current landing gear configuration would work as expected. This was mitigated through series of checks against critical cases and regulatory requirements.

The structural risk identified in this design was found in the pintle mount, upper and lower side stay mount, and the landing gear beam. As shown in ***figure 18***, the said mounts and landing gear beam were placed close to the flap. This may impede the kinematics of the flaps and the landing gear. In addition, at critical load cases it may distribute load onto other parts of wing box connected to the flaps and affect the structural integrity. To mitigate this, it was suggested to install health and usage monitoring systems to detect internal cracks generated within the affected area.

Technical risk found in the landing gear design was the methods used for weight estimations which was based on parametric methods and crude estimations. This discounted many factors and does not take account into bogie geometry. This was mitigated through validation using different methods and comparison to established landing gear design used by current aircrafts in the market. In addition, there were no stress analysis on the breakdown of the components in the landing gear to check its structural and material integrity and failure modes. This does not encourage more suitable choices of materials for each components of landing gear.

In conclusion, the technology used in this landing gear design was established to be matured even before EIS 2025 and inherited low technological risk levels. This is important to keep DOC as low as possible by avoiding unnecessary development and manufacturing costs for landing gear.

5. WAYS OF WORKING

In the pre-PDR stage, an N^2 diagram was established to understand the relationship between different specialist. This was important to determine how one area affects the other. In ***Figure 21***, the flow chart explains the iteration process for the landing gear.

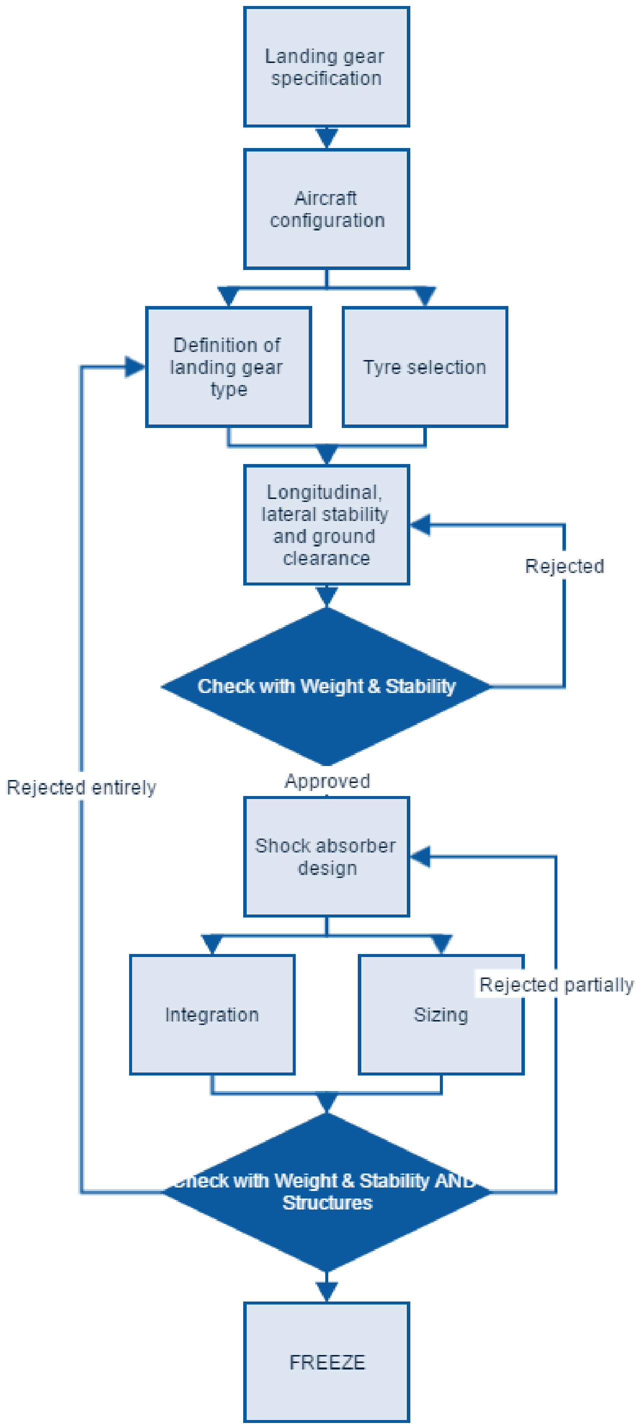


Figure 21: Flow chart of iteration process

In the early stage of design, the landing gear configuration was checked regularly with Weight & Balance specialist to ensure moment equilibrium during off and on ground operations. This was also met with few geometrical constraints such as the fuselage upsweep point and placement of wings which placed limitations on landing gear placement. Initial definition of landing gear and tyres were made and selected using parametric study and estimation methods and updated with each iterations. This was then compared to aircrafts of similar weight.

In post-PDR stage, integration of landing gear was met with few challenges as there were series of changes in fuselage and wing structures. In the final iteration, the landing gear was placed behind the wing to achieve stability. To counteract this, the APU units were placed on the rear fuselage to allow forward shift in landing gear position. This solution avoided extended landing gear beam design which could have caused significant weight penalty and structural complexity.

There was an overall design change in fuselage to shift the fuselage upsweep point aft to allow for shorter landing gear. The integration of landing gear was also challenged by space available for landing gear bay. In the later stage of iterations, the fuselage cross section was made wider to allow stowage of landing gear without needing to add height. This was consistent with the design philosophy and our aim to achieve high utilisation and lower DOC.

6. CONCLUSION

oVal landing gear has been designed carefully with other specialists' area to fulfil the specified requirements as shown in ***Table 22***. The final design for the landing gear was consistent with our initial key driver to achieve high utilisation, minimum weight, reduced life cycle cost, and satisfying regulatory and safety requirements. The design process was iterative and covered aircraft configurations, definition of landing gear type, tyre selection, definition of landing gear location, definition of landing gear components, preliminary sizing, and weight calculations. It is important to carry out more refined methods and validation process before freezing the landing gear solution. In conclusion, the landing gear has achieved targeted landing gear height for high utilisation and a satisfactory landing gear weight.

Table 22: Requirement verification

Requirement	Output	Check
Tip back angle	21.9°	✓
Take-off rotation	14.9°	✓
Nose collapse clearance	Yes	✓
Roll clearance angle	14.0°	✓
ICAO Code D turning circle clearance	10.1m	✓
ICAO Code D outboard track	8.6m	
Turnover angle	46.2°	✓
Ground clearance	Yes	✓

7. REFERENCES

[1] R. K. Schmidt, Landing Gear Tutorial, Bristol University, 2015

[2] N. Currey, Aircraft Landing Gear Design: Principles and Practices, United States: AIAA Education Series, 1988.

[3] E. Torenbeek, Synthesis of Subsonic Airplane Design, Delft University Press, 1982

[4] W. H. M. Sonny T. Chai, “Landing Gear Integration in Aircraft Conceptual Design,” March 1997. [Online]. Available: http://www.aoe.vt.edu/aoe/faculty/Mason_f/M96SC.html. [Accessed 11 10 2015]

[5] Goodyear, “Goodyear Aircraft Tire Data Books,” [Online]. Available: http://www.goodyearaviation.com/resources/pdf/db_airdatabook.pdf. [Accessed 12 10 2015].

[6] Nevoret, P., Landing, H., Systems, G., From, H., World, S., Gear, E. L., … Landing, M. (n.d.). Recent Advances in Electrical Landing Gear Systems, 3–4.

[7] Ivt, G., & Kit, E. (2009). White Paper, 1–9.

[8] COMFAA, version 3.0 [Online]. Available: http://www.faa.gov/airports/engineering/design_software/ [Accessed 11/11/2015]

[9] Landing Gear Design [Online]. Available: http://faculty.dwc.edu/sadraey/Chapter%209.%20Landing%20Gear%20Design.pdf [Accessed 9/10/2015]

Appendix A: A comparison among various landing gear configuration (10: best, 1: worst) [9]

	Tricycle	Quadricycle	Multi-bogie
Cost	4	2	1
Weight	7	9	10
Manufacturability	7	9	1
Take off/landing run	10	5	8
Stability on ground	9	10	8
Stability during taxi	8	10	9

Appendix B: A comparison between MLG attachment

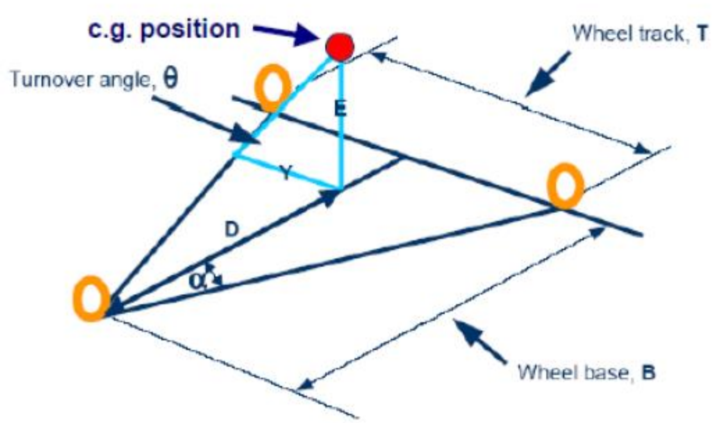
Wing-mounted MLG	Fuselage fairing-mounted MLG
+Wider wheel track	+Shorter landing gear
+Aerodynamically efficient	-Weight penalty
+Good lateral stability	-Aerodynamic penalty
-Structural issues with flaps	-Structural complexity
-Integration issues due to location of MLG placement	

Appendix C: Definition for turnover angle calculation [1]

Lateral location of MLG affects turnover angle and ground clearances.

Turnover angle should be below 63 deg for land based aircraft and 54 deg for carrier aircraft.

Calculation of θ : $\alpha = \text{Tan}^{-1}((T/2)/B)$, $Y = D \sin \alpha$, $\theta = \text{Tan}^{-1}(E/Y)$.



Appendix D: Method for tyre sizing and critical case loading

	Equation	Value	Unit
Tyre Sizing MLG			
Max Static MLG load	MTOW*0.85*1.07	159,162	kg
Single tyre operating load	Max Static MLG load / no. of wheels	22,236	kg
Goodyear MLG Tyre Data			
Tyre type		46, 18, R20	
Rated pressure		205	psi
Static rated load		51,900	lbs
Diameter		46	inch
Width		18	inch
Rim size		20	inch
Tyre Sizing NLG			
MLW	0.85*MTOW	148,750	kg
Wheel base, B		28.4	m
Sink speed, Vs		10.00	ft/s
Max Static Load	0.13*MLW	19,357	kg
Braking load	Vs*H* W / (g*B)	8,356	kg
Single tyre operating load	(Max static load + braking load) / 2	13,847	kg
Goodyear NLG Tyre Data			
Tyre type		40, 15, R16	
Rated pressure		195	psi
Static rated load		55,700.00	lbs
Diameter		40	inch
Width		15	inch
Rim Size		16	inch

	Equation	Value	Unit
Braked Roll Condition			
FZ (AC)	1*0.88*MTOW	154,160	kg
FZ (AC)	1.2*0.88*MLW	157,243	kg
Fz (LG)	FZ (AC) / no of MLG legs	78,621	kg
Fx	Fz (LG) * 0.8	62,897	kg
Fx per tyre	Fx / no of tyre per strut	15,724	kg
Fx per tyre	Fx / no of tyre per strut	34,666	lbs
0.5g Turning Case			
P	0.88*MTOW/2	77,080	kg

VN	0.13*MTOW	22,773	kg
V1+V2	W-VN	152,408	kg
V1-V2	0.5*W*Z/Y	76,817	kg
dP	(V1-V2)/2	38,408	kg
V1	P+dP	115,488	kg
V2	P-dP	38,671	kg
Left MLG	0.5*V2	19,335	kg
Left MLG per tyre		10,656	lbs
Right MLG	0.5*V1	57,744	kg
Right MLG per tyre		31,826	lbs
NLG	0.5*VN	11,386	kg
Take Off Bump			
Fz	1.7*0.88*MTOW/no. of MLG legs	131,036	kg
Fz per tyre		36,110	lbs