

Stress Analysis & Dynamics

Module Code – ACMA5010

**Designing the structural support for a
front automotive wing for a new race
series**

William David Davies

Student Number – 2114617

UWTSD



(Chokani, 2019)

Table Of Contents

Introduction.....	3
Task 1	4
A)	4
B)	6
Task 2	8
The First Recognised Automotive Front Wing	8
The First Front Wing in Formula 1 Racing	8
Formula 1 Car evolution throughout the Years.....	9
Looking forward into the future.....	10
Task 3	11
The First recognised front wing on a racing car	11
The Lotus 49B Front Wing.....	11
Current Formula 1 Racing Car	12
Task 4	13
Conclusion.....	14
References	15
Appendix.....	17

Introduction

In this assignment the team have been tasked with designing the structural support for a front automotive wing for a new race series. In order to complete this successfully, the team have conducted in-depth research into the subject area to find out known values and theories which have been proven over the years of automotive development, particularly in Formula 1. Once designed the team have gone on to highlight the hugely beneficial developments made to the automotive front wing, the manufacturing techniques that have allowed these to be achieved and how they are currently tested in order to give a good idea on how the team could effectively test their design.

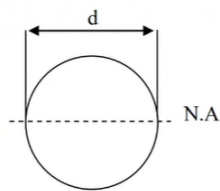
Task 1

A)

All formula used are given derivations which can be found below:

$$y_{\max} = \frac{-WL^4}{8EI}$$

$$I = \frac{\pi d^4}{64}$$



Manual Calculation to verify Excel formula sheet:

Assuming that the load across the wing is Uniformly Distributed:

$$y_{\max} = \frac{-wL^4}{8EI}$$

Using known values:

$$10mm = \frac{-500 \times 1^4}{8 \times 210 \times I}$$

In order to derive I:

$$I = \frac{-w \times L^4}{y_{\max} \times 8 \times E}$$

Using known values:

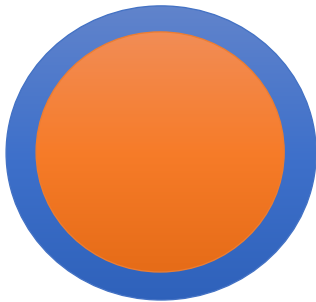
$$I = \frac{(-500 \times 0.825^4)}{0.01 \times 8 \times 210000000000}$$

$$I = 1.378721401E-08$$

These calculations allowed the attached excel sheet to be generated:

Appendix 1

Verification of excel calculations:



External Diameter: $I = \frac{\pi D^4}{64}$ Internal Diameter: $I = \frac{\pi d^4}{64}$

$$I = \frac{\pi D^4}{64} - \frac{\pi d^4}{64}$$

Simplified to:

$$I = \frac{\pi}{64} (D^4 - d^4)$$

$\therefore$

$$I = \frac{\pi}{64} (D^4 - d^4)$$

$$I = \frac{\pi}{64} (0.02794^4 - 0.02394^4)$$

$$I = 1.3790 \times 10^8$$

Inputted back into original derivation:

$$\gamma_{max} = \frac{-wL^4}{8EI}$$

$$\gamma = \frac{-500 \times 0.825^4}{8 \times 210 \times 10^9 \times 1.37744 \times 10^8}$$

Final Answer = 9.99mm

Given this final answer shown the given tube thickness will just be on the limit under the applied force of 500Kg, the race wing is able to perform under the 10mm permissible bend movement.

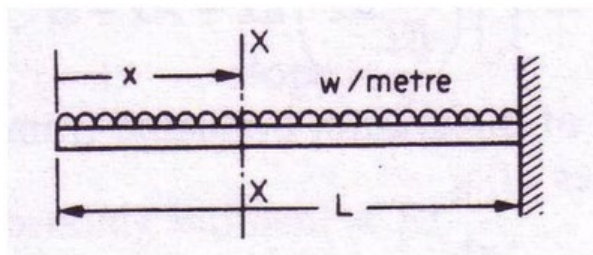
Knowing that this is under the limit the recommendation would be to utilise a 28mm standard diameter pipe to incorporate a factor of safety into the design to ensure it is well within the limits.

B)

Assumptions Made:

Due to the limited data provided, several assumptions were made in order to complete the calculations, these include:

- The front wing is a cantilever beam from a fixed position (front Nose of the car) this then allowed the team to utilise the derived formulas.



- The downforce acting on the front wing is a Uniformly Distributed Load
Justify the weight and length values from research, even though in real terms with changing environmental conditions such as wind and the road surface would mean the downforce would be made up a points loads.
- When conducting research it was found that front wing downforce during F1 racing usually acts between 400N to 600N dependent on the track and other environmental conditions. (Groote, 2003)
- Due to constant developments within the Formula 1 car designs and FIA regulations changing, going from current research the front wing of a formula 1 cars total width is between 1800-2000, due to this front wing being designed for a much lower powered car the value was established to be 1700mm taking half of this for the calculation the single wing span was determined to be 850mm. (jja9128, 2018)
- Due to the diameter of the pole being an unknown, a trial and error activity was used through an Excel spreadsheet to confirm the diameter used. Once this was confirmed, it was decided that the next whole number tube dimension would be used in order to allow the off the shelf diameter to be purchased and keep manufacturing costs down.

Alternative Methods Of Calculation:

As mentioned in the previous section, establishing a point load at the end of the cantilever beam could have been used to complete the calculations, this method would have given the same result but would have taken a considerable amount of time more to complete with more margin for error.

One other method of establishing the required data would have been to model the design and complete CFD and wind tunnel testing if the funds were available.

Task 2

When looking across the full spectrum of automotive front wings, it is clear to see that there has been a huge amount of time and money invested in improvements to get to where we are today. In order to fully understand the developments/evolution of the automotive front wing, the best area to look within the automotive world is the Formula 1 race car. Although high performance road cars are starting to adopt the same theories and methodologies to increase performance and vehicle efficiencies, the most resource invested in development can be seen in the F1 circuit.

The First Recognised Automotive Front Wing

Looking deeper into the development of the front wing in automobiles, the first evolutionary design can be seen in Jim Halls Can-Am Racing Car, the Chaparral 2 in 1963. As can be seen in the image below the vehicle was designed to deflect the air around the tyre, whilst applying significant aerodynamic down force upon the vehicle to allow better grip, which in turn allowed for better performance and stopped the wheels from lifting off the ground.

(Rong, 2017)



(Rong, 2017)

The First Front Wing in Formula 1 Racing

This concept was quickly recognised by the Formula 1 industry, with the first formula one front wing being the 1968 Lotus 49B. Where formula one had historically been heavily reliant on the use of wide and softer tyres for improved grip and performance, team Lotus had introduced a very simplistic yet revolutionary front wing design which then produce negative lift or more commonly referred to as “down-force.” This was found to be a revolutionary introduction to the F1 car with the team realising that the improved road to tyre adhesion produced better handling ability through corners, which is just as important as powerful engines for fast lap times. In addition to improving the handling ability of the vehicle around the track, the aerodynamic down-force allowed a greater transmission of thrust through the tyres which in turn resulted in increased acceleration. (Team Lotus, 2022)

When looking at the overall design of the initial front wing, it can be seen to be very simplistic. This wing was designed to mainly focus on keeping the front nose of the vehicle down and maintaining the best possible contact between the tyres and the road surface beneath it. This can be referred to as the negative angle of attack. The secret behind this wing design is to create the perfect angle of the wing, if the angle is too extreme it would have had the opposite effect, whereby if the angle is (Team Lotus, 2022) too high the airflow is not able to follow the wing low pressure profile and starts to detach from it which leads to lifting forces being increased rather than having the desired effect.



Formula 1 Car evolution throughout the Years

As can be seen in the image, there has been a huge amount of technical advancements and design changes throughout the year of Front Wings in the Formula 1 Race car.



When broken down a critically analysed, there has been several major changes to the design over the years. These are:

(Oggioni, 2019)

The level of adjustment on the wing:

When looking at today's F1 cars the teams have huge amounts of adjustments that can be made in order to perfect the layout of wing flaps, strakes and end plates. This gives a huge advantage over the original designs as these alterations can now be made very quickly.

The Introduction of end plates:

The introduction of the end plate was one of the biggest initial developments of front wing design in F1. This end plate acted as essentially a deflector plate for the airflow over the top of the front wing, which delays the flow detachment, therefore increasing the down-force on the wing by essentially capturing more air flow and not allowing it to escape. (Oggioni, 2019)



The reduction in ride height:

(Motorsport, 2006)

This design has been developed over the years off of the basis that, the lower to the ground it is; the smaller the cross sectional area of the wing will be. In a steady condition the mass flow rate of air passing through the wing, a reduction in the cross sectional area, balanced by increased air speed will lead to lower air pressure distribution on the lower surface of the wing, therefore reducing drag significantly. In today's vehicle they have reached a point where they can no longer go any lower to

ground height as they run the risk of blocking airflow between the wings outer boundary level and the ground beneath it. (Oggioni, 2019)

The increase in the number of wing flaps:

When looking further into study of the airflow on mutli-element wings (increased wing flaps) the airfoil cambers are greatly increased when comparing the results to a single flap, without experiencing flow detachment. (Oggioni, 2019) The flaps are overlapped slightly in order for the upper flap to have its peak minimum pressure very close to the trailing edge of the lower flap, which leads to beneficial upwash that prevents detachment. Although the slotted areas should be an minimal as possible, they have now been designed in a way that they are large enough to allow general debris which is in the racing environment to pass through without having any detrimental effects to the vehicle. These flaps act as vortex generators, which increase/often regulate the levels of down force.



(Somerfield, 2014)

The introduction of Strakes:

Strakes have been introduced from 2017 onwards in order to further deflect air around the tyres and the later part of the cars body. There are huge amounts of different configurations and designs in order to reduce the “wake” (waste airflow after being passed through/over the front wing) which reduces drag on the tyres and the outer body of the car (Oggioni, 2019).



Looking forward into the future

Formula 1

When looking into the vast amount of development that has occurred over the years, it is felt that the focus from now on will be further refinement in the overall wing flap layouts and the materials used to produce these wings. With technologies ever advancing, it is believed that further improved materials/composites will be utilised in order to improved overall strength and impact resistance to further reduce damages incurred during races. The one thing that will have a significantly negative impact are the F1’s regulations which severely limit the technological development of the front wing due to unfair racing advantages. (jjn9128, 2018)

Road Cars

With the current energy crisis, it is believed that the overall reduction of drag on a road car will be further explored in order to improve overall vehicle efficiencies and reduce wastes. (EESI, 2021)

Task 3

Over the years there has been many different developments made when it comes to manufacturing automotive front wings, especially when looking into Formula 1. Within this section of the report, we will be looking at how different front wings are manufactured across the automotive spectrum throughout the years.

The First recognised from wing on a racing car

When looking deeper into the manufacturing processes behind Jim Halls Can-Am Chaparral 2, it was found that the entire body of the car was manufactured from pressed/formed aluminium sheet metal. During this time it would've been one of the lighter weight metals available and perfect for the body of a racing car. The very important thing to remember is that metals, such as aluminium, can undergo plastic deformation, which means that it can take on almost any shape. In order to create the desired shape of the front wing a press die would have been manufactured through machining large blocks of hard metals (harder/tougher than the pressed metal) into 2 pieces. The top and bottom of the press. Once the desired shape is achieved, a mechanically operated press drives the punch against the sheet metal, forcing it into a simple die with the required amount of pressure to produce a permanent change in the metals shape via plastic deformation. (BBE, 2021)



Once pressed this sheet would then be mechanically fastened to the rest of the vehicles body using, nuts, bolts and/or rivets. The structural support of this front wing comes from the chassis of the vehicle.



(Forum, 2018)

The Lotus 49B Front Wing

Similar to the Chaparral 2, the Lotus 49B was constructed from Aluminium sheet metal which has been formed via the sheet pressing process. The difference between this forming process to initial front wings is that the metal has been formed in a Monoque structure. Monoque is a structural technique in which stresses are reacted by thin membrane or shell material, rather than a collection of beams. This meant, that by utilising and forming the light weight aluminium it allowed the structural rigidity to come from the outer shell and not from structural metal support which add unwanted weight which is extremely undesirable especially in a racing car. This often is fixed

together was rivets and taken from the chassis of the car. This design works very well when put under stress from airflow and the rigidity of the aluminium creates the down-force required without failing under stress. (N/A, 2020)

Current Formula 1 Racing Car

When looking at the Formula 1 Front wing today. It is completely different and utilises very modern manufacturing techniques and materials to give the optimum performance and ultimately reduce as much weight as possible whilst maintaining the structural properties required to withstand racing conditions. Like the majority of the cars bodywork, the front wing is mainly manufactured from Carbon Fibre with various other metals and minerals added in order to regulate the flexibility of the wing. Similar to the monocoque technique used with aluminium, carbon fibre can be formed to be self supportive which significantly reduces the overall weight of the vehicle by gaining the structural support required whilst utilising an extremely light weight material that can be formed into any shape required. (Anderson, 2022)

In order to create the desired shapes organic polymers, consisting of long strings of molecules held together by carbon atoms are combined with a variety of gases, liquids and other materials (polymers and metals in formula 1 front wings case) to achieve the desired results in strength, rigidity and weight. The following steps are undertaken in the manufacturing process:

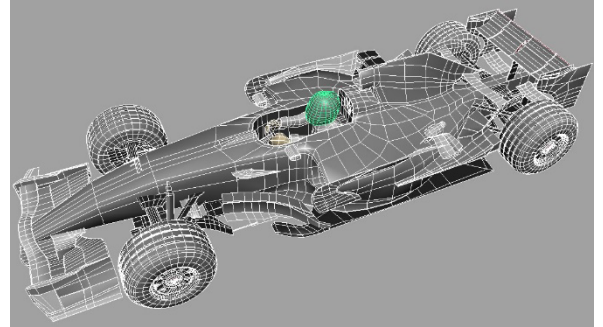
- Carbonisation – Precursors (raw materials) are drawn into long strands and heated anaerobically (oxygen-free) with the extreme heat causing the fibre atoms to vibrate vigorously causing all non-carbon atoms to be expelled.
- Weaving process – once the long and strong carbon atom chain fibres are woven into fabric and combined with other desirable materials such as polymers and metals to achieve the desired elements.
- Surface treatment – stabilised fibres are oxidised to improve bonding properties.
- Forming process – once woven into sheets and treated the carbon fibre material with the desired materials properties woven into it is then formed into the desired shape by creating a desired mold of the shape and placing the fabric into the mould sheet by sheet. Between these sheets, a plastic polymer is applied to bind them all together. When the required number of sheets is reached the top of the mold is then secured tightly and vacuum is applied to further compress the sheets together. Heat can also be applied at this stage to aid the setting process and the mould is allowed to sit for several hours under temperature and pressure in order to mold the desired carbon fibre materials together into 1 solid shape. (Johnson, 2020)

With there being huge amounts of different components which can be altered to suit different racing tracks and conditions, often times the different components are fixed together using traditional fastening such as nuts and bolts in order for them to be easily adjusted through slotted pieces of carbon fibre. With fixed elements of the wings typically being fastened by composites in order to further reduce weight. (Juliana, 2020)

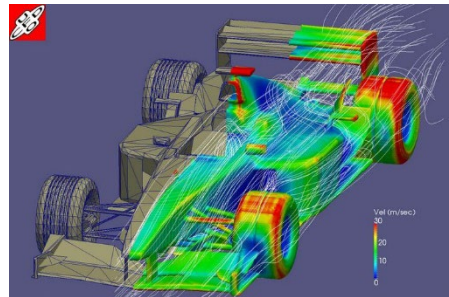
Task 4

To be able to correctly analyse and verify calculations it is deemed essential that a benchmarking activity occurs against the standard F1 testing, this section will outline some of the critical tests that the wing will undergo to comply with FIA regulations (please note that these recommended test methods are not constrained by a budget).

In order to produce a prototype front wing the vital piece of equipment required to start is a high powered PC with a complex and well developed CAD program installed such as CATIA, AutoCAD, Solidworks etc. this will then allow you to develop the proposed design for testing at relatively lost costs and without utilising any very expensive materials prior to initial proof of concept. (N/A, 2019)



Once the initial design is generated it will allow the design team to import the design into specific Fluid Dynamics Simulators such as CFD (Computational Fluid Dynamics). These simulators allow the test team to mathematically simulate the flow of air around and through the front wing and the whole car to model the vehicle behaviour on the track. By utilising this technology it allows teams to create and predict infinite amounts of different scenarios the vehicle will be under on the track and understand how this effects the overall vehicles performance by analysing the front wings ability to handle these certain situations. (N/A, 2017) Finite Element Analysis (FEA) will also be utilised within this stage to pin point areas of potential weakness, which allows for further development and improvement to occur to ensure the final design is exactly what the team requires. (Guimaraes, 2020)



Once happy with the overall design and the majority of the scenarios have been run through using CFD and FEA, a scaled prototype will be produced and set up on a rolling road within a wind tunnel. This will give real life demonstrations of how the wing will react under high speeds and analyse the levels of deflection, drag and down force created.

The result generated from these 2 types of testing will be plotted and analysed to understand the constraints of the design and optimise the performance by pinpointing the areas of lift and drag and implementing solutions to correct this. By plotting these tests we will also be able to understand how the air flow around the wing and look at adding various elements, such as, increasing the number of wing flaps, the addition of strakes in order to better manage the airflow away from the tyres and the rest of the cars main body and potentially reducing the clearance height if the lift on the front end of the car was highlighted as a problem.

Conclusion

To conclude, the team has successfully established the structural support required for the race series front wing and proven out the calculations manually and utilising computer software. This report has also examined the evolution of front wings alongside the technical developments in the manufacturing process which has allowed this evolution to occur. If the opportunity were to arise that the team were able to continue to develop the front wing there has also been recommendations of how this could be tested if there was an unlimited budget.

References

Anderson, G., 2022. *the-race.com*. [Online]

Available at: <https://the-race.com/formula-1/how-f1-2022s-varied-front-wing-designs-work/>
[Accessed 20 September 2022].

BBE, 2021. *bbepressings.co.uk*. [Online]

Available at: <https://www.bbepressings.co.uk/blog/metal-press-work-explained-1>
[Accessed 20 September 2022].

Chokani, D., 2019. *formularapida.net*. [Online]

Available at: <https://formularapida.net/f1-trying-to-have-mushroom-effect-with-2019-wing-changes-for-overtaking/>
[Accessed 20 September 2022].

EESI, 2021. *EESI.org*. [Online]

Available at: <https://www.eesi.org/topics/vehicle-efficiency/description#:~:text=More%20efficient%20vehicles%20that%20run%20on%20lower%20carbon-emitting,liquid%20and%20non-liquid%20E2%80%9Cfuels%E2%80%9D%20derived%20from%20renewable%20sources.>
[Accessed 20 September 2022].

Forum, 2018. *f1150forum.com*. [Online]

Available at: <https://www.f150forum.com/f38/has-anyone-had-repair-replace-their-frame-rail-bumper-mounts-305120/>
[Accessed 20 September 2022].

Groote, S. D., 2003. *f1technical.net*. [Online]

Available at: <https://www.f1technical.net/articles/8>
[Accessed 20 September 2022].

Guimaraes, A. L., 2020. *pinterest.com*. [Online]

Available at: <https://www.pinterest.com/pin/515521488567177190/>
[Accessed 20 September 2022].

jjn9128, 2018. *F1technical.net*. [Online]

Available at: <https://www.f1technical.net/features/21879>
[Accessed 20 September 2022].

Johnson, T., 2020. *thoughtco.com*. [Online]

Available at: <https://www.thoughtco.com/how-is-carbon-fiber-made-820391#:~:text=The%20following%20five%20segments%20are%20typical%20in%20the,oxidized%20to%20improve%20bonding%20properties.%205%20Sizing.%20>
[Accessed 20 September 2022].

Juliana, R., 2020. *motorsportweek.com*. [Online]

Available at: <https://www.motorsportweek.com/2020/08/24/tech-101-how-does-a-formula-1-front-wing-work/>
[Accessed 20 September 2022].

Motorsport, 2006. *motorsport.com*. [Online]
Available at: <https://www.motorsport.com/f1/photos/scuderia-ferrari-248-f1-front-wing/413834/>
[Accessed 20 September 2022].

N/A, 2017. *formula1-dictionary.net*. [Online]
Available at: <https://formula1-dictionary.net/cfd.html>
[Accessed 20 September 2022].

N/A, 2019. *formulaf1results.blogspot.com*. [Online]
Available at: <https://formulaf1results.blogspot.com/2019/06/formula-1-autocad.html>
[Accessed 20 September 2022].

N/A, 2020. *corex-honeycomb.com*. [Online]
Available at: <https://corex-honeycomb.com/monocoque-chassis/>
[Accessed 20 September 2022].

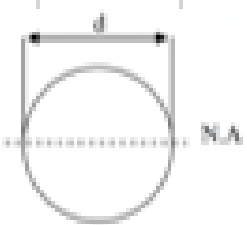
Oggioni, T., 2019. *LinkedIn*. [Online]
Available at: <https://www.linkedin.com/pulse/aerodynamics-formula-one-front-wing-its-evolution-thomas-oggioni/>
[Accessed 20 September 2022].

Rong, B. Z., 2017. *roadandtrack.com*. [Online]
Available at: <https://www.roadandtrack.com/motorsports/a32350/jim-hall-chaparral-2j-history/>
[Accessed 20 September 2022].

Somerfield, M., 2014. *somersf1.co.uk*. [Online]
Available at: <http://www.somersf1.co.uk/2014/11/bite-size-tech-red-bull-rb10-flexing.html>
[Accessed 20 September 2022].

Team Lotus, 2022. *f1technical.net*. [Online]
Available at: <https://www.f1technical.net/f1db/cars/220/lotus-49>
[Accessed 20 September 2022].

Appendix

	Results		
Y max (mm)	0.01	$I = \frac{\pi d^4}{64}$	
W (N)	500		
L (m)	0.825		
E (Gpa)	2.1E+11		
		$y_{max} = \frac{-WL^4}{8EI}$	
Tube thickness (m)	0.002		
I	1.3787E-08		

D (mm)	D (m)	d (m)	I
27.01	0.02701	0.02301	1.23651E-08
27.02	0.02702	0.02302	1.23799E-08
27.03	0.02703	0.02303	1.23947E-08
27.04	0.02704	0.02304	1.24095E-08
27.05	0.02705	0.02305	1.24243E-08
27.06	0.02706	0.02306	1.24391E-08
27.07	0.02707	0.02307	1.2454E-08
27.08	0.02708	0.02308	1.24688E-08
27.09	0.02709	0.02309	1.24837E-08
27.1	0.0271	0.0231	1.24986E-08
27.11	0.02711	0.02311	1.25134E-08
27.12	0.02712	0.02312	1.25283E-08
27.13	0.02713	0.02313	1.25432E-08
27.14	0.02714	0.02314	1.25581E-08
27.15	0.02715	0.02315	1.25731E-08
27.16	0.02716	0.02316	1.2588E-08

27.17	0.02717	0.02317	1.2603E-08
27.18	0.02718	0.02318	1.26179E-08
27.19	0.02719	0.02319	1.26329E-08
27.2	0.0272	0.0232	1.26479E-08
27.21	0.02721	0.02321	1.26629E-08
27.22	0.02722	0.02322	1.26779E-08
27.23	0.02723	0.02323	1.26929E-08
27.24	0.02724	0.02324	1.2708E-08
27.25	0.02725	0.02325	1.2723E-08
27.26	0.02726	0.02326	1.27381E-08
27.27	0.02727	0.02327	1.27532E-08
27.28	0.02728	0.02328	1.27682E-08
27.29	0.02729	0.02329	1.27833E-08
27.3	0.0273	0.0233	1.27984E-08
27.31	0.02731	0.02331	1.28136E-08
27.32	0.02732	0.02332	1.28287E-08
27.33	0.02733	0.02333	1.28438E-08
27.34	0.02734	0.02334	1.2859E-08
27.35	0.02735	0.02335	1.28742E-08
27.36	0.02736	0.02336	1.28893E-08
27.37	0.02737	0.02337	1.29045E-08
27.38	0.02738	0.02338	1.29197E-08
27.39	0.02739	0.02339	1.29349E-08
27.4	0.0274	0.0234	1.29502E-08
27.41	0.02741	0.02341	1.29654E-08
27.42	0.02742	0.02342	1.29807E-08
27.43	0.02743	0.02343	1.29959E-08
27.44	0.02744	0.02344	1.30112E-08
27.45	0.02745	0.02345	1.30265E-08
27.46	0.02746	0.02346	1.30418E-08
27.47	0.02747	0.02347	1.30571E-08
27.48	0.02748	0.02348	1.30724E-08
27.49	0.02749	0.02349	1.30877E-08
27.5	0.0275	0.0235	1.31031E-08
27.51	0.02751	0.02351	1.31185E-08
27.52	0.02752	0.02352	1.31338E-08
27.53	0.02753	0.02353	1.31492E-08
27.54	0.02754	0.02354	1.31646E-08
27.55	0.02755	0.02355	1.318E-08
27.56	0.02756	0.02356	1.31954E-08
27.57	0.02757	0.02357	1.32109E-08
27.58	0.02758	0.02358	1.32263E-08
27.59	0.02759	0.02359	1.32418E-08
27.6	0.0276	0.0236	1.32572E-08
27.61	0.02761	0.02361	1.32727E-08
27.62	0.02762	0.02362	1.32882E-08

27.63	0.02763	0.02363	1.33037E-08
27.64	0.02764	0.02364	1.33192E-08
27.65	0.02765	0.02365	1.33347E-08
27.66	0.02766	0.02366	1.33503E-08
27.67	0.02767	0.02367	1.33658E-08
27.68	0.02768	0.02368	1.33814E-08
27.69	0.02769	0.02369	1.3397E-08
27.7	0.0277	0.0237	1.34126E-08
27.71	0.02771	0.02371	1.34282E-08
27.72	0.02772	0.02372	1.34438E-08
27.73	0.02773	0.02373	1.34594E-08
27.74	0.02774	0.02374	1.3475E-08
27.75	0.02775	0.02375	1.34907E-08
27.76	0.02776	0.02376	1.35063E-08
27.77	0.02777	0.02377	1.3522E-08
27.78	0.02778	0.02378	1.35377E-08
27.79	0.02779	0.02379	1.35534E-08
27.8	0.0278	0.0238	1.35691E-08
27.81	0.02781	0.02381	1.35848E-08
27.82	0.02782	0.02382	1.36006E-08
27.83	0.02783	0.02383	1.36163E-08
27.84	0.02784	0.02384	1.36321E-08
27.85	0.02785	0.02385	1.36478E-08
27.86	0.02786	0.02386	1.36636E-08
27.87	0.02787	0.02387	1.36794E-08
27.88	0.02788	0.02388	1.36952E-08
27.89	0.02789	0.02389	1.3711E-08
27.9	0.0279	0.0239	1.37269E-08
27.91	0.02791	0.02391	1.37427E-08
27.92	0.02792	0.02392	1.37586E-08
27.93	0.02793	0.02393	1.37744E-08
27.94	0.02794	0.02394	1.37903E-08
27.95	0.02795	0.02395	1.38062E-08
27.96	0.02796	0.02396	1.38221E-08
27.97	0.02797	0.02397	1.3838E-08
27.98	0.02798	0.02398	1.38539E-08
27.99	0.02799	0.02399	1.38699E-08
28	0.028	0.024	1.38858E-08