SLIPSTREAM LENGTH/POWER

The slipstream can be thought of as a box which follows each car around the track. Any other cars which enter this box will get a reduction in drag, with the reduction amount determined by the speed of the leading car and the distance to the car behind. The slipstream model goes by the following rules:-

- The higher the speed, the longer the slipstream's influence. Double the speed and the slipstream length increases by a factor of four.
- The higher the speed, the more powerful the slipstream effect. Double the speed and the draft doubles in strength.

GPL's slipstream is not manipulating the car's base drag, nor does it take into account the drag of the car in front. Instead, the effect is described by the mod team as providing a general "air speed discount" to simulate a slipstream-like effect. In the original GPL, at 188mph, the maximum air speed discount at 0 metres distance is **29mph** and the slipstream length is **26 metres**.

Although the necessary section of the code has not been fully investigated, I believe "air speed discount" means the following:-

Each car has a base drag value which GPL (presumably) uses to calculate the car's drag force at any given speed. As the velocity increases, so does the amount of drag, which in turn causes the rate of acceleration to decrease. When the engine no longer has sufficient power to overcome the drag force, the car can no longer increase its velocity and has therefore reached its top speed. The presence of an air speed discount suggests that GPL is measuring the car's velocity and its air speed independently.

There are no wind effects in GPL, so if Car A is doing **168mph** in clean air, it will also have an air speed of 168mph. Assuming a drag coefficient of 0.29 and a frontal area of $1m^2$, the drag force would equal about 1000N (Newtons). If the car continues to accelerate to **188mph**, the drag force will increase a further 25% to 1250N. If Car A now enters the slipstream of Car B, which is also travelling at 188mph, then Car A's apparent air speed will begin to drop, reducing the calculated drag force. Assuming the slipstream is entered at a distance of 17.5m, this would give Car A an air speed discount of 20mph and therefore an apparent air speed of 168mph, allowing it to start accelerating again. Meanwhile, Car B still has 1250N of drag force exerted on it and cannot go any faster. Car A closes the gap on Car B and pulls out of the slipstream to overtake. In clean air the drag force will rise again rapidly, which will soon slow it back down to 188mph. However, if it has built up enough momentum, Car A will be able to complete the pass successfully.

This idea seems to at least explain why "air speed discount" is not the same as "speed gained in the slipstream".

One thing to note is that the draft power will not increase when drafting two or more cars. Each car's slipstream seems to be calculated in memory simultaneously so I presume that the boxes can overlap, but the trailing car will simply benefit from whichever slipstream is the most dominant.

The total slipstream length is capped at around 65 metres, but you would need to do over 295mph to come up against this limit. The caps are probably there to prevent the calculations from drawing additional boxes further down the road (which would work as a 'drag box' instead of a 'draft box').

Tips & Trivia

- The distance vs. draft strength reduction is linear. If the slipstream length is 26m and you are 13m behind the leading car, you will receive 50% of the slipstream's full potential.

- There doesn't seem to be any code which rotates the slipstream box independently of the car, nor does the slipstream follow the car's path, as per the wake behind a boat/jet ski. If the car is at a 45-degree angle to the track, the slipstream is also projected from the rear of the car at the same angle.

- 188mph was the claimed top speed of the Ferrari 312-66 at Reims and it was on the basis of this that the SRMZ team designed all of their physics. I will use the same speed for comparative purposes.

- Olaf Lehmann's dirtgearpatch includes some alterations to the slipstream physics, but only a few critical values were changed and he said at the time he wasn't 100% sure of their function. Anyhow, the slipstream in his dirtgearpatch is about 75 metres long @ 188mph, or 3 times the original GPL's length while the air speed discounts provided are about the same. Olaf's patch caps the slipstream at under 85 metres, meaning if the leading car exceeds over 200mph the tail of the slipstream would be 'cut off'.

WHAT IS ZERO METRES DISTANCE?

In order words, at what point behind the car does the slipstream start?

There are two sections of code dedicated to this. The first part is what Pribluda uses to measure the distance between cars on the track. If you drive up behind another car and touch its gearbox, Pribluda will report a distance of around 4 yards. This is approximately one car's length in GPL and shows that the detection point is at the nose of the car.

However, GPL will not activate the slipstream code until you are more than 2 metres behind this detection point.

The slipstream itself, as determined by a second part of the code, begins roughly around half a metre behind the car's gearbox. This means there is a "deadzone" of up to half a metre behind the gearbox of each car. Observing the code shows that the slipstream effect begins to decrease as you enter this deadzone and so there is actually no advantage to running too close to the car in front.

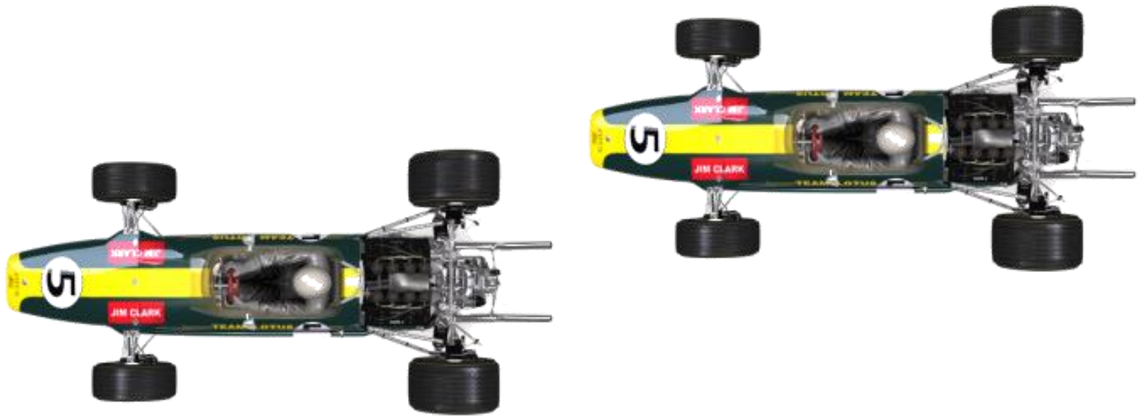
The secondary effect of this is that to allow the AI to gain the slipstream and overtake more successfully, it is perhaps recommended to not have the below value in GPL's ai.ini lower than around 0.5m. Slightly larger values may be even better for mods with smaller cars, like 1965 F1 and 1967 F2, but this is untested at time of writing:

```
passee_dlong_sep_coeff = 0.55 ; modifies desired dlong sep. when tailing designated passee
```

SLIPSTREAM WIDTH

The draft strength also reduces for the trailing car when it is left or right of the leading car's centreline. In other words, to gain maximum benefit from the draft, the player should ensure they are driving perfectly in line with the car in front and not to one side.

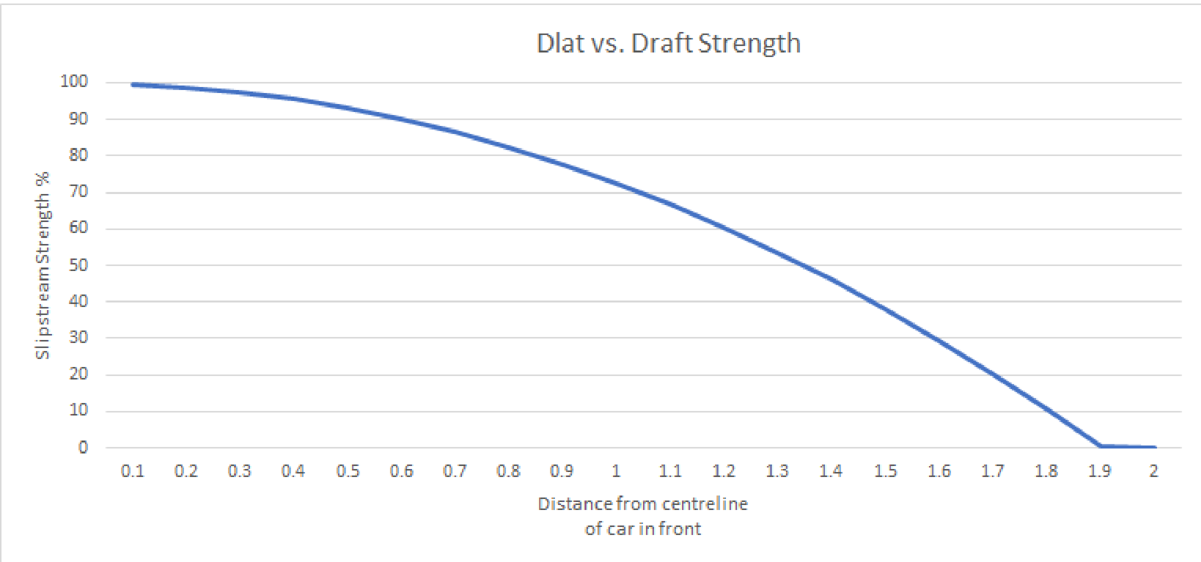
The code is fairly forgiving and you still have over 90% of the draft within the first half metre. Running 1 metre laterally from the centreline (approximately to scale below) would provide the trailing car with around 70% of the draft's full strength:



The draft's total width is around 3.8 metres and is also capped to prevent additional drag boxes from growing out of bounds. Although this sounds much wider than the 1967 GP cars, the draft strength decreases exponentially with lateral distance and in reality, has little influence beyond one car's width.

Even so, the player can still gain a small reduction in drag so long as they do not pull out too far when overtaking, which will help consolidate the pass.

For reference, here is a graph showing the distance from centreline vs. draft strength (car's centreline is at 0):



Tips & Trivia:
Despite claims on the contrary, these parameters modified have been modified in some way for each mod. However, some of the values which must remain in proportion have not been changed accordingly, so some of the calculations are mismatched.

To elaborate, a lot of GPL's variables have to be in harmony with each other to work. For example, if the default of Value A is 1 and Value B is 36, then if you want to increase Value A to 10, you must increase Value B to 360. Although it doesn't seem to cause any critical bugs, the issue is noted.

SLIPSTREAM HEIGHT

Testing has shown that the slipstream does not have a height and there is also no code to reduce the slipstream power based on altitude differences between two cars, for example at a hilly track. The slipstream also cannot be blocked by terrain, so if the lead car disappears into a sharp dip or over the brow of a hill, the slipstream strength will not be impacted at all.

SLIPSTREAM SHAPE

Compiling all of the calculations into a heatmap reveals that the slipstream shape is not a rectangle, tube or a cone but a parabola (or in simple terms, an elongated semi-circle):

(**Speed:** 188mph / **Scale of box**: Approximately 30 metres)

The draft is strongest in the darkest orange areas and decreases as it becomes more yellow. The completely yellow areas are outside of the draft's influence.

Viewed from the side it would seem that the slipstream is extending infinitely above and below the car, so in any case we cannot consider the slipstream 'box' to be a three-dimensional shape.

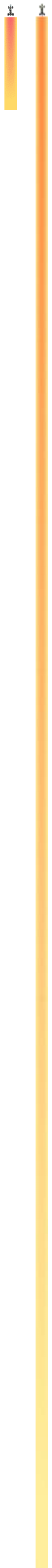
ADDITIONAL FEATURES

When two cars are running closely nose-to-tail in real life, the drag force (+ downforce if the car has aero) can become reduced from the rear of the leading car. This drag reduction can give the leading car a marginal boost in speed.

This effect is also modelled in GPL, with a max air speed discount of just under 2mph being given when the lead car is travelling at 188mph when the trailing car is at 0m distance. Although the effect is slight, even at 10m distance, the air speed discount can be as much as 1mph.

The slipstream code also features what could be considered a rudimentary bump drafting effect. Bump drafting is typically seen in high-speed stock car racing on ovals and allows the car behind to give the car ahead a small push, benefitting both drivers as it increases the lead car’s top speed thus increasing the strength of draft.

In its default state, GPL’s bump drafting effect is so negligible that bumping into the car ahead will only slow you down. However, it does show the engine could have simulated NASCAR without any major modifications. Notably, this code only activates from inside the ‘deadzone’ and when the two cars are physically touching.



NOTES ON THE MODS

Each mod produced by the SRMZ team since 2004 has featured fundamental changes to the slipstream physics in comparison to the original GPL.

According to the team, the goal was to replicate “the sort of drafting trains that were a feature of races at Monza”. The result is that the mods’ slipstream lengths vary from 445 metres @ 188mph in the 1965 F1 and 1967 F2 mods up to 494 metres @ 188mph in the CanAm, Sportscar and 1955 F1 mods. This makes the slipstream’s influence around 17 to 19 times longer than the original GPL’s. Such a slipstream mechanic is unprecedented and has not been adopted by more recent sims like rFactor, GT Legends, Assetto Corsa or iRacing. Many in the GPL community feel it is too excessive.

To show how these two slipstream models compare, the original GPL’s slipstream is shown side-by-side with the most recent mod (1968 F1) in the left margin of this page. The scale of the 1968 car’s slipstream box is 480m, with the slipstream’s influence ending ~95% of the way down the image.

Such a model presents a number of issues for GPL players. Notably that, even when you are barely in sight of the car ahead you are likely to be receiving some kind of drag reduction. It is most noticeable at high-speed circuits like Monza or Reims, where a car which is already well on its way down the straight could be providing a 10-15mph air speed discount to cars which are still exiting Parabolica or Thillois. Normally this benefit would only be felt by exiting the corner from under the gearbox of the car ahead. Their model also introduces a bug into the “leading car speed boost” code – the leading car will get a boost from the car behind from as far as 145 metres away, meaning being slipstreamed from afar can provide the leader with a speed increase.

Two pieces of evidence were cited in support of the SRMZ team’s model – an anecdote from Brabham in which he claims his 1964 F2 car would need to pull out a 400-yard (366m) gap to break the tow[1], and the lap charts for the 1966 French GP where Brabham followed Bandini for 20 or so laps before dropping back.

<u>Analysis of Brabham’s Quote</u>

Without a point of reference, assessing physical distances to within 50 or 100 metres when racing is quite difficult. The same could be said of driving on the road where, if you see a car up ahead, you couldn’t tell with any degree of accuracy whether it was 50m, 150m, or 300m away. The issue when developing a mod is that you need to be more scientific than this.

At Reims in 1964, Brabham spent much of the race battling for the lead and finished side-by-side with winner Alan Rees. His assessment of the distance to the cars behind was perhaps made using his mirrors, which would have been quite small and vibrating heavily at 140mph+, and cannot be regarded as accurate. As the saying goes “Objects in the mirror may appear closer than they are”. Notably, Brabham was also quoted as saying he and Rees pulled out a lead of 500 yards in the closing laps, but the gap to 3rd place Ickx was 12.1 seconds at the finish. Judging by the speed at which they would have crossed the line, Ickx could not have been less than 700 to 800 yards behind by this point and archive footage from this race shows he was not in sight.

The mod team admitted that taking Brabham’s F2 anecdote literally led to a slipstream size of 640m @ 188mph which even “beta testers felt […] was too great” so it was arbitrarily reduced by 25%.

1 http://srmz.net/index.php?showtopic=6430&st=20#entry57131

Analysis of the 1966 Reims Lap Charts

The mod team used lap charts from the opening 25 laps to support their hypothesis.

Their analysis makes the following assumptions:

1. Brabham would be 2s a lap slower without a tow. Therefore, any lap times within 2s of Bandini's can be attributed to the tow's effect.
2. Both cars were travelling over the line at 188mph. Therefore, distance in metres can be calculated from the time gap.
3. He was in the tow until Lap 22 when some backmarkers got in his way

Why 2 seconds? According to the lap charts, Brabham's overall lap times were within 0.7 to 1.5 seconds of Bandini's until lap 22 when, as one race report apparently stated (source unknown), he got caught up behind backmarkers and lost the tow. His times dropped from consistent 2:13s until Lap 22 into the 2:14s (2s a lap slower than Bandini)) and he started falling back. According to the mod team, he would have been between 540m and 788m behind the leader when this occurred, which fitted in with their hypothesis of a 640m draft @ 188mph.

Why 188mph? This was the estimated top speed of the Ferrari in practice, measured before the Thillois hairpin. The mod team used this to estimate the distance in metres between the Brabham and the Ferrari as they crossed the line at the end of each lap. E.g. 188mph = 84 metres per second, therefore a 1.5s gap = 126 metres.

However, both assumptions are highly problematic.

Firstly, there are factors which are likely to have been considerably more influential than tow on lap times. Most notably - small driving errors, changes in lines or braking points as they explored the limits, keeping revs low to maintain engine/oil/water temps and to conserve fuel, not pushing 100% lap after lap to prevent driver fatigue, and so on. In terms of the actual gap, Brabham started dropping away from the Ferrari as early as Lap 12, with a 2.1s gap increasing to 8.8s at the end of Lap 22. The lap times set by Brabham on L15-20 were all consistently within 0.3s of each other, yet the gap grew from 3.9 to 6.2s over this period. On laps where Brabham gained ground, Bandini had a slower lap than usual. The fact that Brabham could keep a consistent pace yet still lose time to the Ferrari shows that the slipstream had no influence at all by this point. The main reason why Bandini started to pull away was because he increased his pace to the 2:12s, while Brabham ran all but one of his race laps in the 2:13s or slower. Brabham's fastest lap was completed on Lap 2, when he crossed the line just 0.7s behind Bandini, and I would argue this was only one of two occasions where he actually entered the Ferrari's slipstream during the race.

Secondly, it can be said with almost certainty that neither driver crossed the S/F line at 188mph. This was Ferrari's estimated top speed in practice, most likely on low fuel, and Brabham's car was not even capable of that speed by a long shot. In the race, Bandini had 120kg of fuel onboard at the start, the lap times were around 5-6 seconds slower than in qualifying meaning top speeds would have been lower too. Furthermore, the Ferrari's top speed was measured at the end of the 3.3km long run between Muizon and Thillois, which featured a steep downhill section that would have helped the cars gain extra speed. In comparison, the distance between Thillois and the S/F line was only 1.3km. With the help of GPL, I estimated that the actual speed across the line was no more than 160-165mph. If true, this would shrink all of the mod team's measurements by over 15%. Indeed, when doing a frame-by-frame analysis of the TV coverage of the 1966 French GP, the final 300m of the lap (as measured on Lap 5 between the pit entry line and S/F line) were traversed by Bandini in 4.16s and by Brabham in 4.22s. This puts their speed at 161mph and 159mph respectively.

Although the approach used by the mod team is somewhat reasonable, the primary issues are caused in the interpretation of these two sources, as well as the lack of supporting evidence.

Alternative Sources

There are several alternative sources which were potentially available at the time of the mod's release that contest their hypothesis.

First is the Motorsport Magazine report of the race, which said Brabham was only "hanging onto the very end of the Ferrari's slip-stream as they finished the first lap". [2] They crossed the line just 1.3s apart, which puts Brabham at 92 metres behind Bandini @ 159mph. In support of this, Lotus aerodynamics engineer Peter Wright (1995), said of 1960s Grand Prix cars, "If the driver accelerates from some 50 metres back behind the car in front, while in its slipstream (drivers claim that they can feel the effect up to 100 metres behind), he will be travelling around 5 kph faster when he comes right up behind it".[3] Driver Jean-Pierre Beltoise (1967) claimed in L'Auto that the slipstreaming effect began at around 50m distance at Reims.[4] An article by journalist Denis Jenkinson (1969) estimated a 5 to 10mph boost starting from approximately 90 metres behind at Monza, "Down a long straight the second car will drop back to 100 yards for example, at 160 m.p.h., rush up into the vacuum behind the leading car so that it approaches at 165-170 m.p.h., pull out and use the momentum to carry it past and into the lead." [5] Although Beltoise's and Jenkinson's ideas suffer from the same issues as Brabham's in terms of distance measurement, Wright had actual scientific/mathematical knowledge of aerodynamics and had developed Lotus's ground effects in 1977. Crucially, all sources support a useful slipstream length of no more than 50-100 metres, with the latter being the maximum possible extent of its reach.

In addition to this, Brabham's top speed in both clean air and the slipstream was published in The Motor magazine's 1966 report following the French GP. At Spa, Brabham's BT19 achieved a max of 172mph on the run to the Masta kink, while at Reims, it touched 174mph, perhaps aided by the downhill section after Muizon. In the slipstream, he was able to gain 8mph meaning a top slipstream speed of 182mph.[6] However it is not clear if this was achieved during practice or in the race.

My approach to GPL's slipstream physics

When developing the now unavailable Slipstream Patch v1.00[7], I focused primarily on the top speed data and the TV coverage of the 1966 French Grand Prix, which would have been unavailable at the time of the 1966 mod's release. This allowed me to physically measure the distance between the two cars at different points on the lap and more accurately assess the slipstream effect.

I went through many versions and tested it against multiple mods before settling on a slipstream length of **41.5 metres @ 188mph**, with the Brabham BT19 able to gain an 8-9mph boost when

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[2] https://www.motorsportmagazine.com/archive/article/august-1966/15/the-52nd-grand-prix-of-the-acf
[3] https://web.archive.org/web/20150908005729/https://www.grandprix.com/ft/ft00196.html
[4] http://srmz.net/index.php?showtopic=6430&st=20#entry57091
[5] https://www.motorsportmagazine.com/archive/article/october-1969/28/monza-afterthoughts
[6] https://forums.autosport.com/topic/163363-1960s-race-speeds/?p=9834503
[7] https://www.youtube.com/watch?v=uhkZCYPZMWY

exiting Muizon from around 10-15 metres behind. At the time, I was not sure how the code worked and so primarily used Pribluda to help me measure the gaps and speed benefit as I somewhat randomly changed the values.

1 year after the development/release of the patch, I was able to analyse the slipstream model used in Assetto Corsa for the Lotus 49. Although AC uses an air pressure discount and is not linear with distance, I recorded AC's slipstream length to be **42.7m @ 190mph**. With GPL's slipstreaming code this would have worked out at 41.8m at 188mph. Considering AC calculates aerodynamics from air pressure and mathematical formulae used in fluid dynamics, this is extraordinarily close to the final values I settled for in Slipstream Patch v1.00.

In reality, there is no real hard data or scientific papers publicly available on slipstreaming and much of what we have is guesswork and estimations. It is likely that a CFD model could help determine how much drag the 1967 cars produced and help find the correct slipstream parameters, but this kind of effort is probably not worth it for a 25-year-old game.