A Theoretical Investigation Into The Increased Speed Of White Miatas Due To Surface-Photon Interaction

Leon van Dommelen L.L. van Dommelen

April 1, 2013

Abstract

A theoretical investigation is conducted to understand why white Miatas, (and more generally white sports cars), are faster than cars of other colors. It is shown that under conditions of thermal equilibrium, white Miatas experience reduced photon drag. Under nonequilibrium conditions, in particular on sunny days, white Miatas may actually experience enhanced propulsion depending on the position of the sun.

1 Introduction

Figure 1: A white Miata and a nonwhite one.

The Miata is a sports car developed by the Japanese car manufacturer Mazda. Figure 1 shows a white and a nonwhite Miata.

The Miata[1] was introduced in the USA market in 1990. It is definitely important to recognize that the Miata was primarily designed for the USA market. However, it was also very successful in other markets. Here are some languages in which the praises of the Miata were sung:

[1] Mazda refers to the Miata commonly as the MX-5. The designation *Miata* has been dropped altogether in recent years.

English
(Spanish) Español
(Greek) Ελληνικά
(Russian) Русский
(CJK) 中日韓
(High UTF-8)

Consider what Homer had to say at the start of the Iliad:

> μῆνιν ἄειδε θεὰ Πηληϊάδεω Ἀχιλῆος
> οὐλομένην, ἣ μυρί᾽ Ἀχαιοῖς ἄλγε᾽ ἔθηκε,
> πολλὰς δ᾽ ἰφθίμους ψυχὰς Ἄϊδι προΐαψεν
> ἡρώων, αὐτοὺς δὲ ἑλώρια τεῦχε κύνεσσιν
> οἰωνοῖσί τε πᾶσι, Διὸς δ᾽ ἐτελείετο βουλή,
> ἐξ οὗ δὴ τὰ πρῶτα διαστήτην ἐρίσαντε
> Ἀτρεΐδης τε ἄναξ ἀνδρῶν καὶ δῖος Ἀχιλλεύς.
>
> τίς τ᾽ ἄρ σφωε θεῶν ἔριδι ξυνέηκε μάχεσθαι;
> Λητοῦς καὶ Διὸς υἱός: ὃ γὰρ βασιλῆϊ χολωθεὶς
> νοῦσον ἀνὰ στρατὸν ὄρσε κακήν, ὀλέκοντο δὲ λαοί,
> οὕνεκα τὸν Χρύσην ἠτίμασεν ἀρητῆρα
> Ἀτρεΐδης: ὃ γὰρ ἦλθε θοὰς ἐπὶ νῆας Ἀχαιῶν
> λυσόμενός τε θύγατρα φέρων τ᾽ ἀπερείσι᾽ ἄποινα,
> στέμματ᾽ ἔχων ἐν χερσὶν ἑκηβόλου Ἀπόλλωνος
> χρυσέῳ ἀνὰ σκήπτρῳ, καὶ λίσσετο πάντας Ἀχαιούς,
> Ἀτρεΐδα δὲ μάλιστα δύω, κοσμήτορε λαῶν:
> Ἀτρεΐδαι τε καὶ ἄλλοι ἐϋκνήμιδες Ἀχαιοί,
> ὑμῖν μὲν θεοὶ δοῖεν Ὀλύμπια δώματ᾽ ἔχοντες
> ἐκπέρσαι Πριάμοιο πόλιν, εὖ δ᾽ οἴκαδ᾽ ἱκέσθαι:
> παῖδα δ᾽ ἐμοὶ λύσαιτε φίλην, τὰ δ᾽ ἄποινα δέχεσθαι,
> ἁζόμενοι Διὸς υἱὸν ἑκηβόλον Ἀπόλλωνα.

Clearly then, life was not pleasant before the coming of Miatas. It is better to drive one small Miata than to sail a thousand ships.

Needless to say, white was a Miata color from the beginning. However, early white Miatas had a problem where the paint would peel off the cars. The issue of Miata-photon interaction first received significant popular attention at this stage. Owners with peeling paint noticed that their cars did not only look worse. The cars also became very noticeably slower when the paint peeled off.

Since then, the increased speed of white Miatas became well known among knowledgeable owners. However, some others doubted the association and acquired grey, black, and even red Miatas. While these Miatas would still drive at reasonable speeds, they had difficulty competing with the white ones when maximum performance was an issue.

Table 1: First-generation Miata colors produced, in cars. Data compiled by John Emerson. Figures provided by Marketing Division of Mazda Corporation, Irvine, CA. Posted on miata.net. Data are resorted in order of increasing car speed, scaled with rated engine power. Data for 1990-1991 white Miatas are applicable until the paint peels off.

Year:	1990	1991	1992	1993	1994	1995	1996	1997	all
Classic red	29195	16000	11729	8415	6013	4888	4006	3950	84196
Black			4626	6111	5741	4877	4063	3702	29120
BRG green		3997							3997
Marina green								3000	3000
Starlight blue							3000		3000
Merlot						3500			3500
Twilight blue								1500	1500
Montego blue					3003	2818	5742	4571	16134
Yellow			1515						1515
Mariner blue	6540	3633	2096	1082					13351
Laguna blue					1788	440			2228
Silver stone	3481	5802	1475						10758
Chaste white					3565	2945	2160	1929	10599
Crystal white	12420	8855	5195	5874		122			32466
Totals	51636	38287	26636	21482	20110	19590	18971	18652	215364

Table 1 lists the various colors in which the first-generation Miata was produced. They are sorted by car speed, relative to engine power. (Table 2 shows the same data sorted by total cars produced.)

At first, some features of table 1 may seem surprising. For example, you might reasonable assume that black Miatas would be slower than red ones. After all, black will absorb all colors of light, while red absorbs only nonred ones. However, black Miatas are notoriously difficult to keep clean. Because of the great variations in surface temperatures, dirt gets "baked" on. So black Miatas reflect a good deal of light due to the dirt.

Table 2: Like the first table, but sorted by total cars produced.

Year:	1990	1991	1992	1993	1994	1995	1996	1997	all
Twilight blue								1500	1500
Yellow			1515						1515
Laguna blue					1788	440			2228
Marina green								3000	3000
Starlight blue							3000		3000
Merlot						3500			3500
BRG green		3997							3997
Chaste white					3565	2945	2160	1929	10599
Silver stone	3481	5802	1475						10758
Mariner blue	6540	3633	2096	1082					13351
Montego blue					3003	2818	5742	4571	16134
Black			4626	6111	5741	4877	4063	3702	29120
Crystal white	12420	8855	5195	5874		122			32466
Classic red	29195	16000	11729	8415	6013	4888	4006	3950	84196
Totals	51636	38287	26636	21482	20110	19590	18971	18652	215364

You might also wonder why the slower colors, and especially red, sold quite a large number of cars. The reason is psychological. A significant number of owners are somewhat wary of the speed of their Miatas. In private communications, Miata owners have told the author that it feels "somewhat scary, so without a roof in a small, fast, car." The reduced speed of red Miatas provides some sense of reassurance. Many red Miata owners also end up installing a hardtop on a semi-permanent basis.

At the other side of the list, you find the hard-core enthusiasts who go for speed. (To be sure, some white Miata owners might also be attracted by the fact that the white Miatas do not need much effort to look clean. But surely, that is a small minority.)

Another observation that may be surprising at first is why a yellow Miata might best several blue ones. After all, photon energy increases from red to yellow to green to blue. Actually, the yellow Miata has a lot of white thrown in. In addition, various blue Miatas are really dark. While they do emit some blue, they absorb colors of all wavelengths.

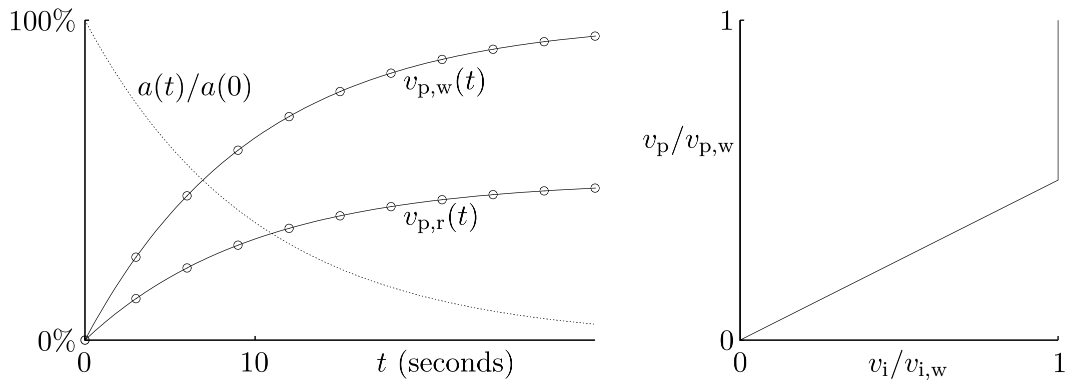

Figure 2: Left: Speed difference between a white and a red Miata. This uses plot units. Right: the nonlinear stretching used to clarify the speed difference.

The left-hand graph in Fig. 2 compares the speed $v(t)$ of a red Miata to that of a white one. Here v is the velocity and t the time in seconds from rest. Subscripts w and r indicate the white and red Miatas, respectively. The velocity is taken relative to the terminal velocity of the white Miata. The acceleration $a(t)$, relative to the initial one $a(0)$, is also plotted. (The relative acceleration is the same for the Miatas, although the absolute acceleration of the red Miata is of course less.) For simplicity, CVT mode is assumed.

To clarify the speed difference, the velocity has been plotted on a slightly nonlinear scale. The right-hand graph shows this scaling. In it, v_{i} is the indicated speed and v_{p} the plotted speed. Note that this correction is reminiscent of the difference between indicated airspeed and true airspeed in aviation. The plotted speed takes here the place of the true airspeed in aviation.

Mathematically, the velocity correction is given by

$$\frac{v_{\mathrm{p}}}{v_{\mathrm{p,w}}} = \frac{1 + e^{1990^2 (v_{\mathrm{i}} - v_{\mathrm{i,w}})/v_{\mathrm{i,w}}}}{2}$$

Note that 1990 is the model year of the first Miatas. For convenience, the above curve can be approximated as piecewise linear.

The purpose of this paper is to shed some theoretical light on the described empirical observations. It will be shown that special relativity combined with quantum mechanics directly implies the speed advantage of white Miatas. Therefore, the speed difference is not an experimental aberration but a scientific fact.

2 Theoretical Background

The Miata-light interaction is obviously described by the two pillars of modern physics, special relativity and quantum mechanics. Since the reader is surely well aware of quantum electrodynamics, either in Feynman's path integral approach or in canonical formulation, it needs no introduction. However, a few key results will be summarized in subsections 2.1 and 2.2 for ready reference. For more information, see [2, pp. 1-152]. A more easily accessible source may be [8].

2.1 Special relativity

The speed of any Miata is small, but not vanishingly small, compared to the speed of light. (There are some mathematical issues associated with the previous statement that will be addressed in a planned second volume of this book.) Therefore relativistic mechanics must be used.

Einstein's famous relation

$$E = mc^2 \tag{1}$$

implies that a moving Miata picks up additional mass.

However, the principle of relativity, as first formulated by Poincaré, allows the viewpoint of a driver inside the Miata. Physics is the same regardless of the relative motion of the observers. The driver viewpoint will frequently be used in the current paper to simplify the arguments.

The most important relation for the purpose of this paper is the relativistic Doppler shift. The equation that governs the difference in observed wavelength λ of light, and the corresponding difference in observed frequency ω, between moving observers is

$$\begin{aligned} \lambda_v &= \lambda_0 \sqrt{\frac{c+v}{c-v}} \\ \omega_v &= \omega_0 \sqrt{\frac{c-v}{c+v}} \end{aligned} \tag{2}$$

Here the subscript 0 stands for the emitter of the light, and subscript v for an observer moving with speed v away from the emitter. If the observer moves towards the emitter, v is negative. (To be true, the formulae above apply whether the observer 0 is emitting the light or not. However, in most practical applications, observer 0 is indeed the emitter.)

Of course, Miatas do not drive in vacuum but in the atmosphere. Fortunately, this effect may be ignored as secondary on light propagation as long as no significant H_2O in liquid form is present. (In any case, Miatas are known to disagree with these so-called “rain” conditions.) However, the atmosphere is very important because of aerodynamic drag. These issues will be addressed further in subsection 2.3.

2.2 Quantum mechanics

Schrödinger, in his famous equation, associated energy with the partial time differentiation operator, and linear momentum with the partial space differentiation operator in a given direction:

$$E \quad \Longleftrightarrow \quad i\hbar\frac{\partial}{\partial t} \qquad p_x \quad \Longleftrightarrow \quad -i\hbar\frac{\partial}{\partial x} \tag{3}$$

Here $\hbar$ is the scaled Planck’s constant and i is $\sqrt{-1}$.

The above results are of critical importance for this paper, because the Miata-light interaction is due to exchange of the energy and momentum of photons of light. Therefore, it is helpful to make the above relations specific for photons:

$$E = \hbar\omega \qquad p = \hbar\frac{\omega}{c} \tag{4}$$

These expressions are known as the Planck-Einstein and de Broglie relations. They may be derived by applying Schrödinger’s associations on a complex, propagating monochromatic light wave. As is well known, the first expression is consistent with Einstein’s relation (1) in view of the fact that photons have zero rest mass.

2.3 Aerodynamics

The primary factor limiting the maximum speed of a Miata is aerodynamic resistance. This resistance is related to boundary layers along the surface of the Miata in which the air is being dragged along. Going downstream, this air forms a wake behind the Miata. The wake is the primary cause of resistance, [see 3, pp. 570-571].

The wake is always relatively wide because the boundary layer separates from the surface at some point, [5, 7, 6]. This greatly increases the aerodynamic resistance. Controlling separation remains a difficult problem, [4].

There is also the problem that the boundary layer is normally turbulent. By itself, turbulence will increase drag due to its thermodynamically irreversible mechanics, [9]. However, often transition to turbulence decreases drag instead because it also tends to delay separation.

The high speed of, in particular, white Miatas, will also bring in compressibility effects, [1]. Note that such effects are largest in elevated speed areas such as near the top of the windshield header.

3 Photon-Surface Interactions

Figure 3: Photon-surface interaction mechanisms. They depend on photon wavelength. Photos © Leon van Dommelen.

At this stage, the photon-surface interaction can be understood to the required detail. Figure 3 above shows how an incoming photon of light, γ, interacts with a white and a nonwhite Miata. The white Miata will reflect or emit photons of all colors. However, a red Miata will mostly emit red photons.

If a red Miata absorbs a blue photon and releases its energy as heat, the momentum of the photon is gone. The red Miata has effectively stopped the photon. Because of Newton's third law, action equals minus reaction, the red Miata experiences an opposite force slowing it down. That would hold even if all the photon energy was emitted again as omnidirectional infrared radiation.

On the other hand, as illustrated in figure 3, the white Miata leaves the backward moving momentum of the photon largely intact, assuming a predominantly specular emission. The vertical momentum does change more significantly. However, that merely presses the white Miata more strongly onto the road, providing an additional measure of safety at its higher speeds.

(As the Planck-Einstein and the Broglie relations show, photon energy is proportional to momentum. It is not proportional to square momentum, as Newtonian physics would suggest. Therefore, if a red Miata re-emitted all incoming photon energy as radiation, and if that radiation was predominantly specular with respect to the incoming photon, then there would not be a difference between the Miatas. Unfortunately, neither condition is true.)

You might of course wonder whether the advantage of the white Miata would not be offset by photons coming from other directions. There is something to that. It should be stressed that a Miata, of any color, in an equilibrium situation with blackbody radiation coming from all directions, will *not* experience a net force. Any other statement would obviously violate the second law of thermodynamics. And this paper would never suggest it would not. Only the highest standards of scientific integrity are applied in this work.

However, for a *moving* Miata, the photons coming from the front are *blueshifted*. That is described by the relativistic Doppler shift (2). This increases their energy, and as a result, a moving Miata on an otherwise equilibrium earth experiences a photon drag slowing it down. Photons like the example in figure 3 dominate. As a result, the Miata will experience a photon drag. However, a white Miata will experience less drag because it slows down the dominant photons less.

It is also interesting to look at nonequilibrium situations. In particular, on sunny days the photon distribution is far from a blackbody one. Photons come predominantly from a concentrated source: the sun. Now if the sun is in front of the Miata, figure 3 showed that a white Miata experiences less photon drag.

You might now of course conjecture that if the sun is in the back, then this advantage could reverse. That in that case, a red Miata might have an advantage. Unfortunately, that is not true. Figure 4 shows what happens. In this case, there is a "solar sail" effect. This effect, well established for interstellar travel, actually provides a propulsive force for the Miata. Now if a photon is simply absorbed by a red Miata, its momentum adds to that red Miata. However, if a photon is reflected by a white Miata, *double* its momentum is added to that white Miata. Of course, the real situation is more complex. A white Miata is not a perfect reflector, and a red Miata not a perfect absorber. Figure 4 tries to capture the average situation. Still, the white Miata experiences a much greater solar sail effect.

Figure 4: The solar sail effect.

There is another important effect that Miata owners often ignore. The high-energy radiation absorbed by a red Miata comes out primarily as heat. Now heated air at the surface of the red Miata wants to rise away from the Miata because it is lighter than the surrounding air at the same pressure. Clearly, that will promote separation, the primary effect limiting the speed of a Miata. True, the rising air will also promote turbulence, which might delay separation a bit. However, it is to be expected that global buoyancy will dominate and separation will be promoted. This will greatly increase the aerodynamic drag of a red Miata.

On the other hand, current work by the author and Yapalparvi, (in progress), suggests that the lower surface temperatures of a white Miata will generate a "Görtler" vortex system that may be very efficient in delaying separation. Figure 5 shows the expected motion of the system. Note that this represents just a very small segment of the thin boundary layer, looking upstream.

With the advantageous photon interaction, in addition to the enhancement of the aerodynamics by the Görtler system, the much higher speed of white Miatas is clearly fully explained.

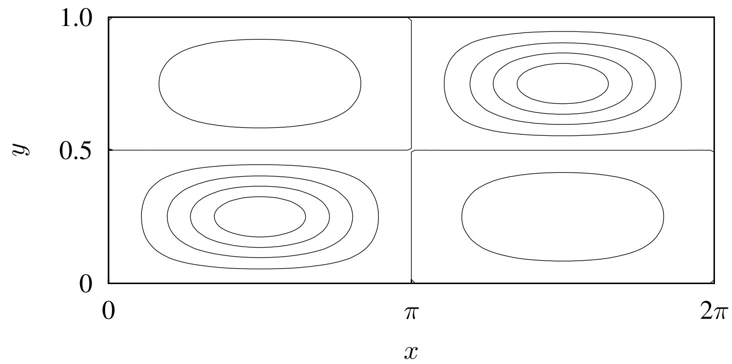

Figure 5: Görtler vortex system in the boundary layer on a white Miata at speed. Inferred from theoretical observations by Van Dommelen and Yapalparvi.

4 Concluding Remarks

The claim that white Miatas are noticeably faster than other ones, and in particular red ones, is commonly considered with considerable skepticism. It is often argued that this experimental observation is due to observational bias of some Miata owners and is not supported by independent verification. The analysis in this paper, however, clearly shows that such skepticism is unjustified. For solid theoretical reasons, white Miatas cannot be anything else than faster than other colors.

A More Details

This appendix has deliberately been left empty, to convey the sense of peace and quiet that comes from driving a Miata.

References

[1] J. Ackeret, F. Feldmann, and N. Rott. Investigations of compression shocks and boundary layers in gases moving at high speed. Technical Report NACA Tech. Memo. 1113, ETH Zurich No. 10, 1947.

[2] R. P. Feynman. *QED, the Strange Theory of Light and Matter.* Princeton, expanded edition, 2006.

[3] L. Prandtl. Über Flüssigkeitsbewegung bei sehr kleiner Reibung. In *Ludwig Prandtl gesammelte Abhandlüngen*, volume 2, pages 575–584. Springer-Verlag, Berlin, 1961.

[4] S.F. Shen and Z-h Xiao. Towards the optimization of control of unsteady separation. Private communication, 1987.

[5] L. L. Van Dommelen. *Unsteady Boundary Layer Separation*. PhD thesis, Cornell University, Ithaca, NY, 1981.

[6] L. L. Van Dommelen and S. J. Cowley. On the Lagrangian description of unsteady boundary-layer separation. Part 1. General theory. *J. Fluid Mech.*, 210:593–626, 1990.

[7] L. L. Van Dommelen and S. F. Shen. The genesis of separation. In T. Cebeci, editor, *Symposium on Numerical and Physical Aspects of Aerodynamic Flows*, pages 293–311. Springer-Verlag, 1982.

[8] Leon van Dommelen. Quantum mechanics for engineers, 2004-... URL `http://www.eng.fsu.edu/~dommelen/quantum`.

[9] J.D.A. Walker. Mechanism of turbulence production near a wall. ICOMP seminar series, NASA-Lewis, July 26, 1988.