

Effect of Kei Truck Bed Coverages on Fuel Efficiency

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Abstract

Aerodynamic drag is a primary contributor to fuel consumption at moderate to high speeds in personal and commercial vehicles. Most of these vehicles in the modern day are already built aerodynamically to minimize this drag. Trucks, however, are designed with beds which trap air and lead to vortex creation. This study examines the influence of truck bed geometry on the drag of the vehicle, with a specific focus on Japanese Kei trucks which are used to haul materials across the mountainous terrain of the Japanese islands. Prior research has demonstrated that bed covers do decrease drag in full-size pickup trucks using both computational and experimental approaches, but there is very little research on smaller vehicles operating at lower Reynolds numbers. To address this limitation, three bed configurations – open bed, flat tonneau cover, and a sloped cover – are evaluated using a combined experimental and computational studies. Wind tunnel testing is conducted on a 1/10th scale RC Kei truck model and idealized computational fluid dynamics simulations (CFD) in Siemens NX are used to analyze flow behavior. Drag forces are computed and compared across configurations to assess the significance of observed differences. In agreement with previous work, the open bed configuration is attributed to a larger drag force on the system than the covered configurations, with the flat cover results going along with the literature, but the sloped cover disagreed with previous work, as it exhibited a higher drag than the flat cover. This implies that out of the bed covers being tested, the flat tonneau cover is the most effective. These covers are also typically used on trucks and easy to manufacture, allowing mass production and increase efficiency of many trucks. In the future, a refined model should be applied in the CFD analysis, and an advanced mounting system is required for the physical test in the wind tunnel.

Introduction

Improving fuel efficiency in ground transportation remains a central challenge in mechanical and automotive engineering. For light-duty trucks, aerodynamic drag is a dominant force at moderate to high driving speeds and directly impacts fuel consumption [1]. The issue is especially significant for compact utility vehicles such as the Japanese Kei Truck, which are commonly used to transport goods through mountainous and rural regions where fuel stations may be sparse. Due to these vehicles operating under strict size constraints and relatively low engine power, minimizing aerodynamic losses can meaningfully improve both fuel economy and operational reliability. One important geometric feature that influences drag is the truck bed, which has been shown to alter the surrounding pressure field [1].

Previous research has investigated the aerodynamic performance of pickup trucks with and without bed covers using both Computational Fluid Dynamics (CFD) [2] and other numerical methods such as finite element analysis [3]. The findings through these

experiments are consistent with established fluid mechanical principles: when high-speed external flow encounters a sudden geometric discontinuity, such as the rear wall of an open truck bed, it promotes vortex formation and enlarges the wake region, thereby increasing aerodynamic resistance [4].

In addition to flat tonneau covers, some researchers have explored geometrically optimized rear cabin extensions or contoured covers to further streamline flow and reduce the wake size and drag. Ait Moussa [3] demonstrated that carefully designed rear cabin modifications with gradual slopes can reduce pressure gradients at the rear of the vehicle. While these studies provide strong evidence that bed covers improve aerodynamic efficiency in full-size pickup trucks, most analyses have focused on generic or larger truck geometries operating at highway speeds [1,3] ($\sim 100\text{km/h}$). There are comparatively less detailed investigations into compact trucks operating at typical urban speeds ($\sim 50\text{km/h}$), where Reynolds number scale may influence the magnitude of drag reduction.

Based on the existing literature and fundamental fluid mechanic principles such as pressure distribution, turbulence, and flow separation, the team believe that the presence of a flat-bed cover will decrease the aerodynamic drag on the truck and that a bed cover geometry can be created to decrease the drag forces even more. The team plan to quantify this with a t-test which can find if there is a real correlation to drag reduction vs a control group without a cover. To analyze this, the team will use the purchased model Kei trucks and will collect data in the wind tunnel and correlate the data to drag forces for analysis towards the hypothesis. After testing, a CFD simulation will be implemented to validate the wind tunnel results and further analyze the differences in drag between configurations.

Methods

This project addresses the following question: does the geometry of a Kei truck bed cover meaningfully reduce aerodynamic drag, and if so, which cover geometry produces the greatest drag reduction? To answer this question, two data methods are used. First, direct drag force measurements are collected from wind tunnel testing of a $1/10^{\text{th}}$ scale RC Kei truck model. Wind tunnel testing is appropriate because it provides controlled repeatable force measurements under defined flow conditions with all other variables held constant., making it well suited for isolating the bed cover geometry as the only independent variable. Second, $1/10^{\text{th}}$ scale idealized CFD simulations are performed in NX to analyze flow behaviour that cannot be directly seen in the wind tunnel. The combination of experimental and computational data strengthens the validity of the results by allowing cross validation between methods.

Manufacturing

Two $1/10^{\text{th}}$ scale RC Kei truck models were ordered from Amazon. These models serve as the physical base for the truck bed configurations. Using these models ensures that the geometry, surface finish and frontal area remain consistent between tests, making the bed cover the only independent variable. The Kei truck body measures 0.338 m length, 0.158 m width as well as height. The frontal area of the truck is well within the 25% blockage limit of the wind tunnel test section with an area of 0.0248 meters squared compared to 0.0550 meters squared. Two units have been ordered to increase testing efficiency.



Figure 1. RC Kei truck model

Three interchangeable bed cover configurations were attached to the RC models including:

- Open bed (control)- no cover; factory RC bed used as is.
- Flat tonneau cover- a flat rectangular panel printed to rest on top of the bed creating a flush surface (Illustrated by the 2D CAD drawing in the Appendix B).
- Sloped cover- a contoured cover inspired by the Tesla Cybertruck rear geometry.



Figure 2. Truck bed configurations in wind tunnel. Open bed (left), flat cover (middle), and sloped cover in (right).

Each cover has been designed in CAD to fit precisely onto the existing truck bed walls. The flat tonneau and sloped cover were 3D printed using PLA filament on a Prusa printer located in Hopeman hall and each cover took around 3 hours to print on a standard build plate. After printing, the covers were sanded to ensure a smooth finish.

A custom mounting block with dimensions of 10 by 5 ½ inches and thickness of ½ inches has been fabricated out of wood and attached to the underside of the RC Kei truck chassis. Wire is threaded through holes drilled in the block and secured to the transmission of the truck. The tires of the truck are secured by 3D printed wheel stoppers (See 2D CAD drawing in Appendix B) epoxied onto the block using J-B Weld two-part epoxy. The block is designed to attach to two vertical ¼-20 threaded rods, connected to a metal plate with three ¼-20 through holes allowing the model to connect with the wind tunnels stinger mount system using ¼-20 nuts. The block took around 1-2 hours to fabricate in the Rettner machine shop and there was an additional wait time of 24 hours for the epoxy to cure. An image of the mounting block configuration connected to the wind tunnel can be seen in the Appendix F.

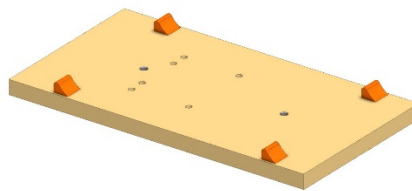


Figure 3. Cad rendering of mounting block with stoppers attached.

Wind Tunnel Testing Plan

The wind tunnel test used a $1/10^{\text{th}}$ scale RC Kei truck model with a length of 13.3 inch (0.338 m), representing a full-scale truck length of about 3.3 m. Reynolds number (Re), which represents the ratio of inertial to viscous force in a flow, is used to ensure aerodynamic similarity between the model and the full-scale vehicle [4]. For air at room conditions, the kinematic viscosity is $\nu = 1.55 \times 10^{-5} \text{ m}^2/\text{s}$ [5]. Thus, the full-scale Reynolds number for an actual Kei truck with length $L \approx 3.3 \text{ m}$ operating at speed $U \approx 13.8 \text{ m/s}$ ($\sim 31 \text{ mph}$) is

$$Re_{full} = \frac{UL}{\nu} = \frac{(13.8 \frac{\text{m}}{\text{s}}) \times (3.3 \text{ m})}{1.55 \times 10^{-5} \text{ m}^2/\text{s}} \approx 2.94 \times 10^6 \quad (1)$$

To approximate aerodynamic similarity between the full-scale vehicle and the model, the wind tunnel speed is determined based on Reynolds number scaling. For a 0.338 m length model, the target Re is chosen to be approximately one-quarter of the full-scale value. This gives $Re_{model} \approx 0.68 \times 10^6$ and corresponds to the required wind tunnel speed of 31 m/s:

$$U_{wind} = \frac{Re_{model}\nu}{L} = \frac{(0.68 \times 10^6) \times (1.55 \times 10^{-5} \text{ m}^2/\text{s})}{0.338 \text{ m}} \approx 31.1 \text{ m/s} \quad (2)$$

The achievable $Re_{model} \approx 0.68 \times 10^6$ is lower than the full-scale value because the wind tunnel speed is limited for safety consideration. This constraint prevents perfect Reynolds number matching and will be treated as a limitation of this project. However, the setup is still acceptable for comparative study because all three configurations are tested under identical conditions.

The truck model will be mounted using a mounting block fabricated out of wood secured to the wind tunnel fixture with a $1/4$ -20 bolt. The model will be restrained with fishing wire to maintain alignment. After testing, calibration will be done using a setup consisting of a nylon string connected to the wind tunnel measurement instrument, a pulley, and known weights. Drag force data will be recorded at a sampling rate of 1000 Hz for 3 minutes in each run. For each run, the mode, orientation, mounting, and wind speed will be held constant. The only variable between tests is the bed-cover geometry.

Each configuration will be tested 4 times. For each run, strain measurements will be recorded directly, and the drag force F_D will be converted using the calibration equation. Because each configuration will only be tested a limited number of times, the results will be summarized using the mean and a 95% confidence interval based on Student's t -distribution [6]:

$$\bar{F}_D \pm t_{0.025, n-1} \times \frac{s}{\sqrt{n}} \quad (3)$$

where $\bar{F}_D$ is the sample mean, s is the standard deviation, n is number of runs, and t is the t -distribution critical value corresponding to a 95% confidence level with $n - 1$ degrees of freedom. Details of uncertainty analysis are discussed in Appendix D. The bed cover design with the lowest mean drag force is considered the most aerodynamically effective.

CFD Testing Plan

In parallel, 1/10th scale idealized CFD simulations will be performed in NX using the same three bed configurations, as shown in Figure 4. Using the laser scanned model shown in Figure 5, an idealized 3d model was created to run the simulation. The model includes aerodynamic features such as the sloped cab, specific bed thickness, side mirrors, and the stiffening ribs on top of the truck for accuracy in airflow. Absent from the model are wheels, headlights, and many of the small details on the sides and underside of the truck. A mesh size of 5mm was applied to the entire system with a more refined mesh on the surface of the truck of 2.5 mm, allowing the simulation to be more precise at those points. The air block used for analysis around the truck was set to the same size as the wind tunnel and given an inlet air speed of 31 m/s and an opening at the outlet.

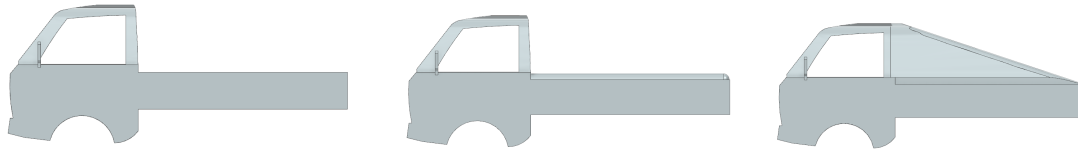


Figure 4. 2D model configurations. Open bed (left), flat cover (middle), and sloped cover (right).

This study used a Spalart-Allmaras (SA) turbulence model, and the solution was run in parallel to speed up the processing. A rudimentary residual maximum was set at 1×10^{-5} ; however, the residuals never reached this value and began to converge around a value of 0.001, leaving room for improvement in both mesh accuracy and detail precision in future experiments to reach this residual maximum. When these residuals reached a constant value and did not continue to fall, the simulation was stopped and the results were taken from this solution. Along with the drag values, streamlines were created to show airflow over the truck and through the bed to more easily visualize vortex creation and aerodynamic flow.

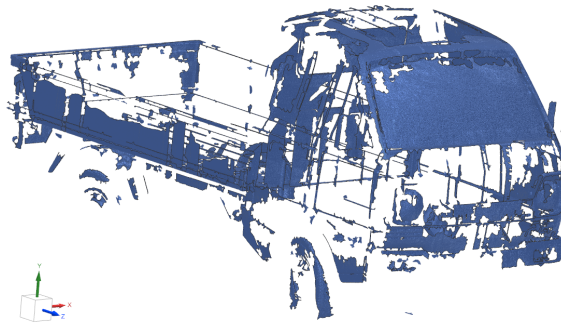


Figure 5. Model obtained using 3d FARO arm scanning

Results

For the wind tunnel, the output was recorded as strain over time, and all measurements first had to be converted to drag force. Since the expected drag range of the mounting apparatus and each bed configuration was unknown before testing, preliminary strain data were collected first, and then separate calibrations were performed for each loading range. The weights used for calibration and linear fit calibration equations were summarized in Table 1:

Table 1: Calibration Data

Configurations	Weights used (oz)	Calibration Equation (F in oz)
Mounting apparatus	15, 16, 18, 20, 22	$F = 746979.885322 \times \varepsilon + 1322.440717$
Open bed	44, 46, 48, 50, 52, 54	$F = 627015.469522 \times \varepsilon + 1122.038109$
Flat bed cover	44, 46, 48, 50, 52, 54	$F = 627015.469522 \times \varepsilon + 1122.038109$
Sloped bed cover	43, 45, 47, 49, 51, 53	$F = 554052.534965 \times \varepsilon + 1000.645125$

Linear fits were applied to the calibration data to relate strain to force. A representative calibration curve was shown in Figure 6, with one sample calibration equation given by $F = 627015.469522 \times \varepsilon + 1122.038109$. The linear trend in the calibration confirmed that strain could be reliably converted into drag for the test conditions.

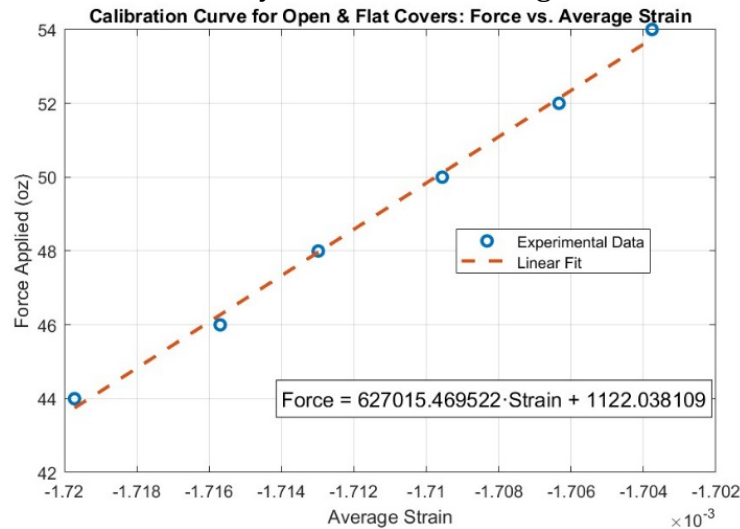


Figure 6. A representative calibration curve for open bed wind tunnel test.

After calibration, each strain vs. time dataset was converted into drag vs. time data, and the mean drag over time was calculated for each trial. The mounting apparatus was tested 3 times, and each bed configuration was tested 4 times. The mean drag from each trial was then used to calculate an overall mean drag and a 95% confidence interval using the t -distribution. A representative drag measurement plot is shown in Figure 7.

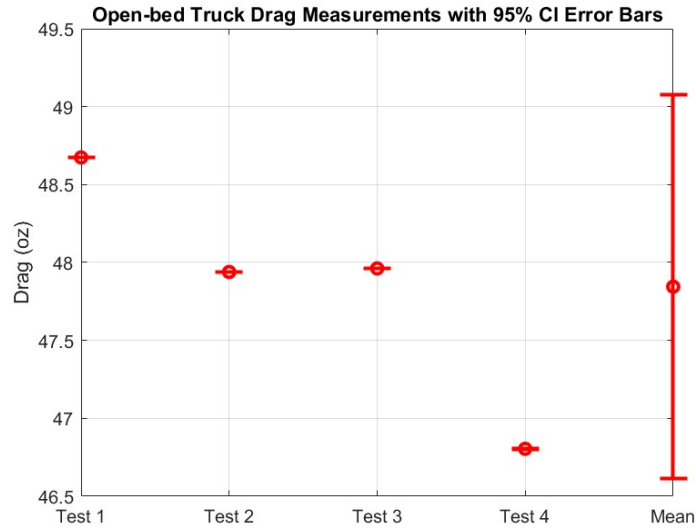


Figure 7. A representative drag plot with 95% CI for open bed wind tunnel test.

Figure 7 shows a representative drag summary plot with the individual trial mean drag and the overall mean. The confidence interval on the overall mean was noticeably larger than the confidence intervals for the individual trials. It was because the overall mean was based on only four trials, giving a much smaller number of degrees of freedom.

The mean drag of the mounting apparatus was tested to be 4.512 ± 0.166 N. To determine the aerodynamic effect of the truck bed alone, this mean drag of the mounting apparatus was subtracted from each bed configuration. The resulting net drag values were compared in Table 2:

Table 2: Net Drag Values

Configuration	Net Drag (N)	95% C.I.	%lower vs Open
Open-bed	8.789	± 0.342	0
Flat Cover	7.931	± 0.288	9.80%
Sloped Cover	8.481	± 0.116	3.51%

Table 2 summarizes that the open-bed case had the highest net drag at 8.789 ± 0.342 N, while the flat cover and sloped cover configurations both successfully reduced the drag to 7.931 ± 0.288 N and 8.481 ± 0.116 N, respectively. Compared with the open bed, the flat cover reduced drag by 9.80%, and the sloped cover reduced drag by 3.51%. These results supported the hypothesis that adding a bed cover reduces drag by limiting the separated flow and vortex formation associated with an open bed. The bar chart with 95% confidence interval in Figure 8 better illustrated this result.

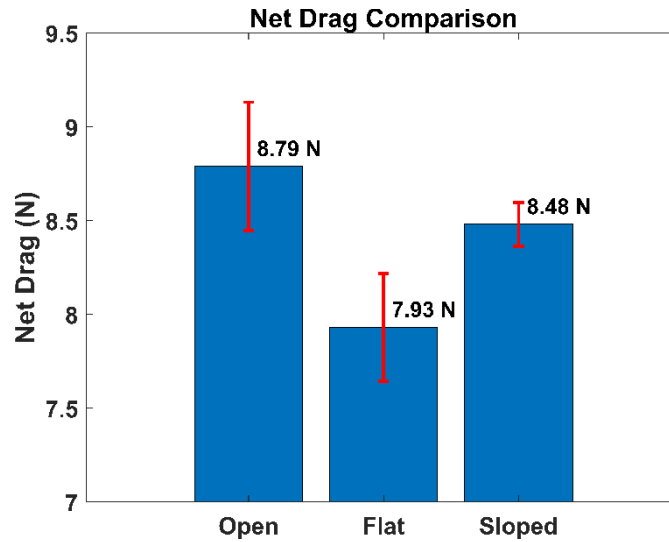


Figure 8. Net drag Comparison with 95% confidence interval.

Figure 8 and Table 2 show that the flat bed cover gave the strongest improvement. Its error bar does not overlap with that of the open-bed case, so this reduction was supported at least at the 95% confidence level. The sloped-bed cover design still exhibits lower drag forces compared with the open bed, but the improvement is smaller than expected.

The NX CFD simulation provided a second estimate of the net drag under the same test condition. 3D velocity streamline plots were used to visualize the flow behavior around each truck bed configuration, shown in Figure 9.

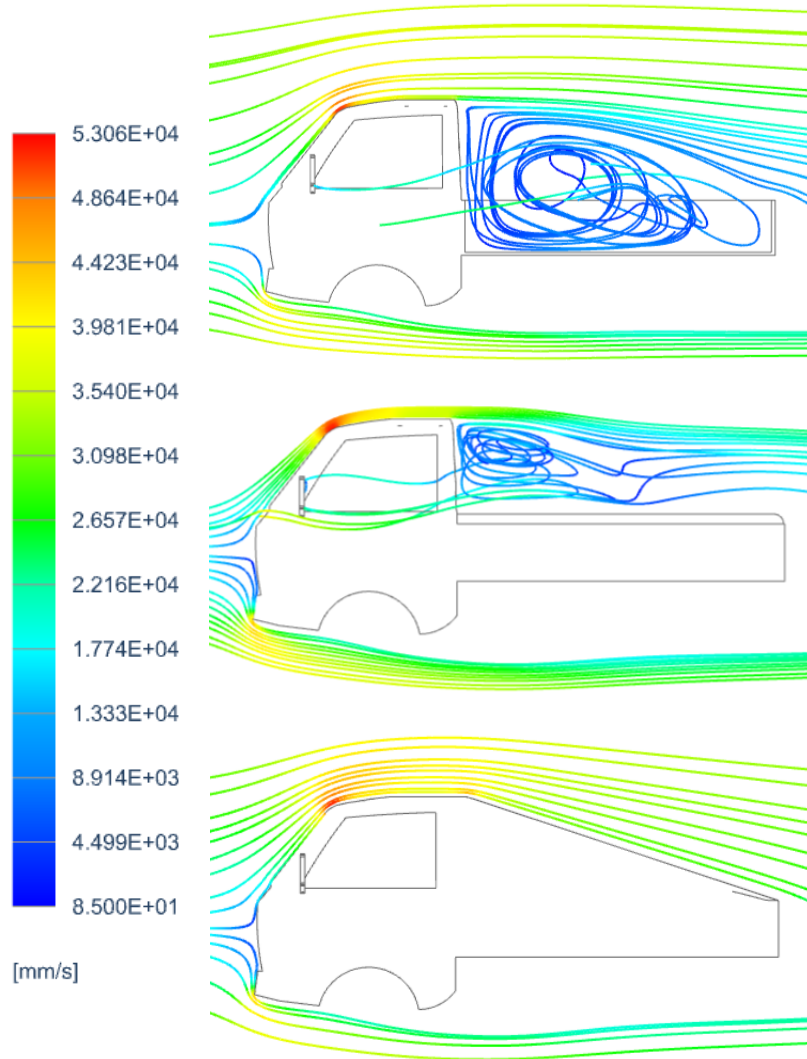


Figure 9. 3D velocity streamlines from NX CFD simulation.

From Figure 9, a large recirculation zone was observed within the truck bed for the open bed configuration. The streamlines showed a strong vortex occupying most of the bed volume, indicating significant flow separation and energy loss due to turbulence. For the flat cover configuration, a much smaller vortex was observed only near the front portion of the cover, and the flow separation was reduced. For the sloped cover configuration, the streamlines showed smooth and attached flow along the surface of the cover. No significant vortex formation was observed. The net drag values obtained from CFD simulations were summarized in Table 3:

Table 3: Net drag from CFD:

Configuration	Net Drag (N)	%lower vs Open
Open-bed	10.974	0
Flat Cover	10.148	7.50%
Sloped Cover	10.765	2.00%

The open-bed configuration produced the highest drag of 10.974 N, while the flat cover reduced the drag to 10.148 N (7.5% reduction), and the sloped cover resulted in 10.765 N (2.0% reduction).

These results showed the same trend as the wind tunnel experiments, with flat covers producing the lowest drag, followed by sloped cover, and open bed had the greatest drag. This agreement between CFD and experimental results further supported the conclusion that adding a bed cover reduces aerodynamic drag, with the flat cover being the most effective design among those tested.

Discussion

The results from both wind tunnel tests and CFD simulations consistently supported the hypothesis that adding a bed cover reduces aerodynamic drag. The open-bed configuration produced the highest drag due to strong flow separation and vortex formation within the truck bed. Both covered configurations reduced drag. The flat cover showed the greatest reduction, followed by the sloped cover. The wind tunnel results demonstrated that the drag reduction for the flat cover was statistically significant at the 95% confidence level, as indicated by the non-overlapping confidence intervals. The CFD results showed the same trend, reinforcing the conclusion that the flat-bed cover is the most effective design.

However, there were several limitations for the wind tunnel test. The use of a 1/10 scale model introduced Reynolds number discrepancies, which may affect flow behaviour compared to full-scale conditions. Surface roughness from 3D printing and minor geometric inconsistencies (e.g. Wheels) could influence flow boundary condition. In addition, the mounting apparatus drag was subtracted to isolate the truck drag, but the frictional force between the truck model and mounting was not considered. Future work can increase the number of wind tunnel trials to reduce uncertainty and provide more reliable statistical results. Moreover, testing at higher wind speeds or using a larger-scale model would help better match Reynolds number conditions.

For the CFD analysis, a mesh convergence study should be implemented to ensure that the simulation can converge at a low residual target for more accurate results. The current simulation results were not convergent, and the residuals were 0.001, which was relatively large for CFD analysis. Additionally, the truck model for the CFD should also be refined with all the details on the RC truck tested in the wind tunnel. The model used now was only an idealized representation for the RC Kei truck, which lost details such as stiffening ribs, special geometry on the truck bed, windshield, wheels, etc. All the missing components could affect the CFD results due to the change of contact surfaces.

Acknowledgements

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Author Contribution

Jason Cao: CFD Analysis, Discussion, Peer Review, Gantt Chart.

Gregory Morrison: CFD Analysis, Introduction, Abstract, Peer Review.

Charlie Cai: Wind Tunnel Data Analysis, Results, Testing Plan, Discussion.

Caleb Granda: Method, Testing Plan, Manufacturing.

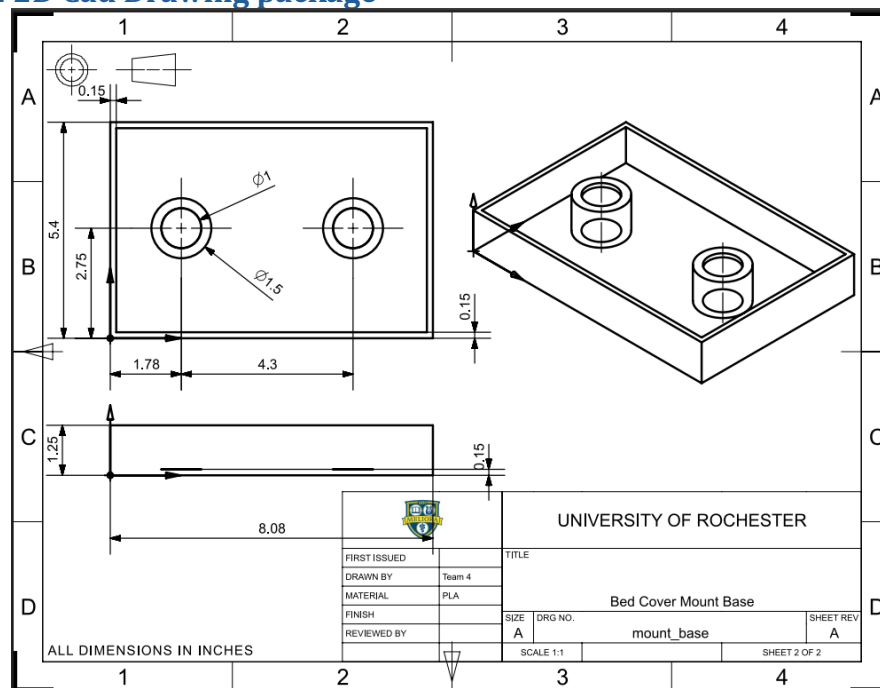
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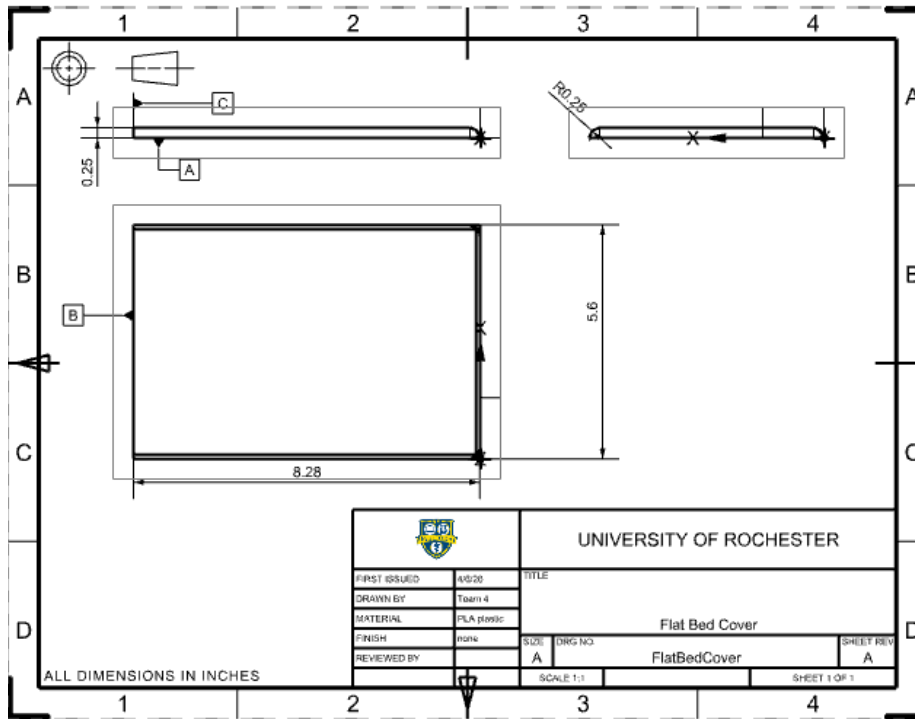
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<https://doi.org/10.31603/ae.14620>
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- [6] Wheeler, A. J., and Ganji, A. R., 2004, *Introduction to Engineering Experimentation*, 3rd ed., Pearson Prentice Hall, Upper Saddle River, NJ.

Appendix A: Project Timeline (Gantt Chart)

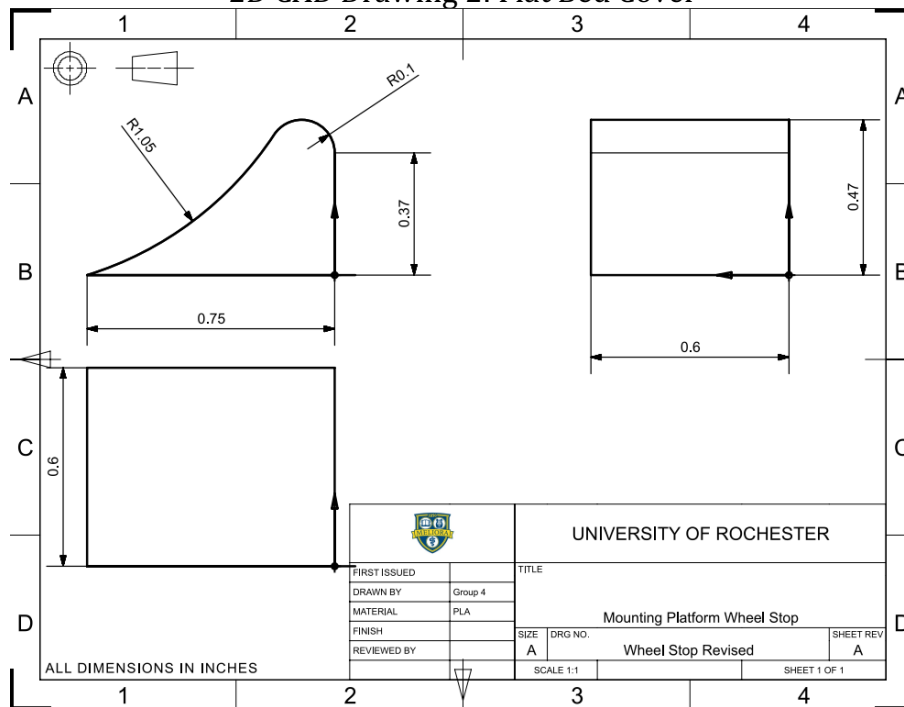
		as of		4/29/2026	input values							
					Week of							
					3/16	3/23	3/30	4/6	4/13	4/20	4/27	
					9	10	11	12	13	14	15	
Stage	input data in cells that are this color	% actual complete	% must be complete	status								
1	Prepare the 3D models for bed cover and mounting device	100%	100%		x	x						
	Laser scan the kei truck	100%	100%					x				
2	Assemble the 3D printed part to the kei truck and mounting device	100%	100%		x	x						
3	Wind tunnel Test	100%	100%				x	x	x			
	Mounting device Test	100%	100%				x	x				
	Kei truck with flat cover	100%	100%				x	x				
	Kei truck with open bed	100%	100%				x	x				
	Progress report draft	100%	100%				x					
	Progree report	100%	100%				x	x				
4	In class presentation	100%	100%					x	x			
5	Data analysis	100%	100%				x	x	x			
	MATLAB code for wind tunnel results for the mounting device	100%	100%					x	x			
	MATLAB interpretation for the flat cover and open bed	100%	100%					x	x			
	MATLAB interpretation for the optimized geometry	100%	100%					x	x			
6	CFD analysis	100%	100%						x	x		
7	Write draft for final paper	100%	100%					x	x			
	Poster draft	100%	100%					x	x			
8	Poster	100%	100%						x	x		
	Final paper	100%	100%							x	x	

Appendix B: 2D Cad Drawing package





2D CAD Drawing 2: Flat Bed Cover



2D CAD Drawing 3: Wheel Stopers

Appendix C: Bill of Materials

item	Order Number	Source	Description (Add Hyperlink if possible)	Quantity	\$/Each	Extended
1	2602241608	Amazon	1:10 scale RC Kei truck.	2	\$ 64.99	\$ 129.98
2	2603092057	Amazon	1.26 inch x 1/8 inch Magnet	1	\$ 9.99	\$ 9.99
3	Verified stock	Verified stock	PLA filament	1	\$ 16.00	\$ 16.00
4	Verified stock	Verified stock	Fishing wire	1	\$ 1.00	\$ 1.00
5	Verified stock	Verified stock	0.5" x 5.5" x 10.5" Wood	1	\$ 1.00	\$ 1.00
6	Verified stock	McMaster	Steel Threaded Rod, 1/4"-20 Thread Size, 6" Long	2	\$ 3.71	\$ 7.42
7	Verified stock	McMaster	Steel Hex Nut, SAE Grade 5, 1/4"-20 Thread Size	1	\$ 6.32	\$ 6.32
8	Verified stock	Amazon	Super Glue	1	\$ 12.49	\$ 12.49
9	Verified stock	HomeDepot	Epoxy for Metal, PVC, wood, concrete, ceramic & tile, fiberglass and glass	1	\$ 7.78	\$ 7.78
Total Cost						
\$					191.98	

Appendix D: Analysis and uncertainty analysis

Representative open bed cover uncertainty analysis

The uncertainty analysis for the wind tunnel measurements was performed in two stages:

- (1) uncertainty within each trial
- (2) uncertainty of the overall mean across trials.

Part I: Single trial statistics

For each trial, the drag force was recorded as a time series with approximately $n \approx 180,000$ data points.

The mean drag for a single trial is given by:

$$\bar{F}_D = \frac{1}{n} \sum_{i=1}^n F_{D,i}$$

The standard deviation of the drag measurement is:

$$s_i = \sqrt{\frac{1}{n-1} \sum_{i=1}^n (F_{D,i} - \bar{F}_D)^2}$$

The 95% confidence interval (CI) for the mean drag of each trial is then calculated using the Student's t -distribution:

$$C.I._i = t_{0.025, n-1} \times \frac{s_i}{\sqrt{n}}$$

Since n is large ($n \approx 180,000$), the t -value approaches the standard normal value:

$$t_{0.025, n-1} = 1.96$$

Thus, for each trial:

$$C.I._i = 1.96 \times \frac{s_i}{\sqrt{n}}$$

Part II: Overall mean across trials

Let the mean drag values from the four trials be: $\bar{F}_{D,1}$ $\bar{F}_{D,2}$ $\bar{F}_{D,3}$ $\bar{F}_{D,4}$

The overall mean drag is:

$$\bar{F}_{D,overall} = \frac{1}{n} \sum_{i=1}^n \bar{F}_{D,i}$$

where $n = 4$.

The standard deviation of the overall means is:

$$S_{overall} = \sqrt{\frac{1}{n-1} \sum_{i=1}^n (\bar{F}_{D,i} - \bar{F}_{D,overall})^2}$$

The 95% confidence interval for the overall mean is:

$$C.I._{overall} = t_{0.025, n-1} \times \frac{S_{overall}}{\sqrt{n}}$$

With $n = 4$ trials, the degrees of freedom is $n - 1 = 3$, giving:

$$t_{0.025, 3} = 3.182$$

Thus,

$$C.I._{overall} = 3.182 \times \frac{S_i}{2}$$

Appendix E: Analysis Code

Part I: Open bed cover calibration code

```
% calibration for open bed & flat bed
% 44oz weight
load("ME241_TruckOpenBedcalibration_44oz_2026-04-08_15-16.mat")
avg44 = mean(d(1000:10000, 2));
oz44 = avg44;
% 46oz weight
load("ME241_TruckOpenBedcalibration_46oz_2026-04-08_15-17.mat")
avg46 = mean(d(1000:10000, 2));
oz46 = avg46;
% 48oz weight
load("ME241_TruckOpenBedcalibration_48oz_2026-04-08_15-17.mat")
avg48 = mean(d(1000:10000, 2));
oz48 = avg48;
% 50oz weight
load("ME241_TruckOpenBedcalibration_50oz_2026-04-08_15-18.mat")
avg50 = mean(d(1000:10000, 2));
oz50 = avg50;
% 52oz weight
load("ME241_TruckOpenBedcalibration_52oz_2026-04-08_15-18.mat")
avg52 = mean(d(1000:10000, 2));
oz52 = avg52;
% 54oz weight
load("ME241_TruckOpenBedcalibration_54oz_2026-04-08_15-19.mat")
avg54 = mean(d(1000:10000, 2));
oz54 = avg54;
% Force Applied vs Average Strain Plot
% Ounces used in each calibration
force_oz = [44 46 48 50 52 54];
% Corresponding average strain values
avg_strain = [-oz44, oz46, oz48, oz50, oz52, oz54];
% Linear fit (1st order polynomial)
p = polyfit(avg_strain, force_oz, 1);
% Generate smooth fit line
strain_fit = linspace(min(avg_strain), max(avg_strain), 100);
force_fit = polyval(p, strain_fit);
% Plot
figure;
plot(avg_strain, force_oz, 'o', 'LineWidth', 2);
hold on;
```

```

plot(strain_fit, force_fit, '--', 'LineWidth', 2);
grid on;
xlabel('Average Strain');
ylabel('Force Applied (oz)');
title('Calibration Curve for Open & Flat Covers: Force vs. Average Strain');
legend('Experimental Data', 'Linear Fit', 'Location', 'best');
%% Display equation
fprintf('Calibration Equation:\n')
fprintf('Force = %.6f * Strain + %.6f\n', p(1), p(2));
eqn_str = sprintf('Force = %.6f*Strain + %.6f', p(1), p(2));
% Add equation to figure
text(-0.001714, 44, eqn_str, 'FontSize', 12, 'BackgroundColor', 'white', 'EdgeColor', 'black', 'Color',
'black');

```

Part II: Open bed cover tests analysis code

```

%% open bed analysis
%% open bed test 1
load('ME241_TruckOpenBedOpenBed_1_2026-04-08_14-25.mat');
t = d(:,1); % time data
strain = -d(:,2); % strain data
drag = polyval(p, strain); % drag in oz

figure; % drag vs T
plot(t, drag, 'LineWidth', 2);
grid on;
xlabel('Time (s)');
ylabel('Drag (oz)');
title('Measured Drag of the Open-bed Truck vs. Time (Test1)');

open_mean_1 = mean(drag); % mean drag over time
drag_std = std(drag); % standard deviation
n = length(drag);
open_CI_1 = 1.960 * drag_std / sqrt(n); % Student t: v=180000, a/2=0.025, then t=1.96

fprintf('Test 1: Open-bed truck average drag = %.6f oz\n', open_mean_1);
fprintf('95%% CI = [%.6f, %.6f] oz\n', open_mean_1 - open_CI_1, open_mean_1 + open_CI_1);

%% open bed test 2
load('ME241_TruckOpenBedOpenBed_2_2026-04-08_14-31.mat');

t = d(:,1); % time data
strain = -d(:,2); % strain data
drag = polyval(p, strain); % drag in oz

figure; % drag vs T
plot(t, drag, 'LineWidth', 2);
grid on;
xlabel('Time (s)');
ylabel('Drag (oz)');
title('Measured Drag of the Open-bed Truck vs. Time (Test2)');

open_mean_2 = mean(drag); % mean drag over time
drag_std = std(drag); % standard deviation
n = length(drag);
open_CI_2 = 1.960 * drag_std / sqrt(n); % Student t: v=180000, a/2=0.025, then t=1.96

fprintf('Test 2: Open-bed truck average drag = %.6f oz\n', open_mean_2);
fprintf('95%% CI = [%.6f, %.6f] oz\n', open_mean_2 - open_CI_2, open_mean_2 + open_CI_2);

%% open bed test 3
load('ME241_TruckOpenBedOpenBed_3_2026-04-08_14-37.mat');

t = d(:,1); % time data
strain = -d(:,2); % strain data
drag = polyval(p, strain); % drag in oz

figure; % drag vs T

```

```

plot(t, drag, 'LineWidth', 2);
grid on;
xlabel('Time (s)');
ylabel('Drag (oz)');
title('Measured Drag of the Open-bed Truck vs. Time (Test3)');

open_mean_3 = mean(drag); % mean drag over time
drag_std = std(drag); % standard deviation
n = length(drag);
open_CI_3 = 1.960 * drag_std / sqrt(n); % Student t: v=180000, a/2=0.025, then t=1.96

fprintf('Test 3: Open-bed truck average drag = %.6f oz\n', open_mean_3);
fprintf('95% CI = [%.6f, %.6f] oz\n', open_mean_3 - open_CI_3, open_mean_3 + open_CI_3);

%% open bed test 4
load("ME241_TruckOpenBedOpenBed_4_2026-04-08_14-43.mat");

t = d(:,1); % time data
strain = -d(:,2); % strain data
drag = polyval(p, strain); % drag in oz

figure; % drag vs T
plot(t, drag, 'LineWidth', 2);
grid on;
xlabel('Time (s)');
ylabel('Drag (oz)');
title('Measured Drag of the Open-bed Truck vs. Time (Test4)');

open_mean_4 = mean(drag); % mean drag over time
drag_std = std(drag); % standard deviation
n = length(drag);
open_CI_4 = 1.960 * drag_std / sqrt(n); % Student t: v=180000, a/2=0.025, then t=1.96

fprintf('Test 4: Open-bed truck average drag = %.6f oz\n', open_mean_4);
fprintf('95% CI = [%.6f, %.6f] oz\n', open_mean_4 - open_CI_4, open_mean_4 + open_CI_4);

```

Part III: Open bed cover overall mean drag analysis code

```

%% average of 4 open bed tests
% mean drag from 4 trials
means = [open_mean_1, open_mean_2, open_mean_3, open_mean_4];
% 95% CI from t distribution
errs = [open_CI_1, open_CI_2, open_CI_3, open_CI_4];
% overall mean
overall_mean = mean(means);
% overall standard deviation
overall_std = std(means);
n = length(means);
% overall error bar by t-distribution
overall_err = 3.182 * overall_std / sqrt(n); % Student t: v=4-1=3, a/2=0.025, then t=3.182

y = [means, overall_mean]; % individual trial + overall mean
e = [errs, overall_err];

% plot
figure;
errorbar(1:5, y, e, 'ro', 'LineWidth', 2, 'CapSize', 15);
grid on;
xticks(1:5);
xticklabels({'Test 1', 'Test 2', 'Test 3', 'Test 4', 'Mean'});
ylabel('Drag (oz)');
title('Open-bed Truck Drag Measurements with 95% CI Error Bars');

% print results
for i = 1:4
    fprintf('Open-bed test %d mean = %.6f oz, 95% CI = [%.6f, %.6f]\n', ...
        i, means(i), means(i)-errs(i), means(i)+errs(i));
end

```

```
fprintf('Open-bed overall mean drag = %.6f oz, 95% CI = [%.6f, %.6f]\n', ...
    overall_mean, overall_mean-overall_err, overall_mean+overall_err);
```

Note: Similar code in Part I, II, III was used for mounting apparatus, flat bed cover, and optimized bed cover analysis.

Part IV: Final bar chart with error bars & result table code

```
% final plot
% overall mean drags in N
mount_mean = 4.5124498; % mounting mean drag
open_mean = 13.3014818; % open bed
flat_mean = 12.4434868; % flat bed
opt_mean = 12.9929092; % optimized bed
% subtracting mounting mean drag
means = [open_mean, flat_mean, opt_mean] - mount_mean;
% errors
errors = [0.3418853 0.2880782 0.1160983];
% plot
figure;
b = bar(means);
hold on;

errorbar(1:3, means, errors, 'r', 'LineStyle', 'none', 'LineWidth', 1.5);

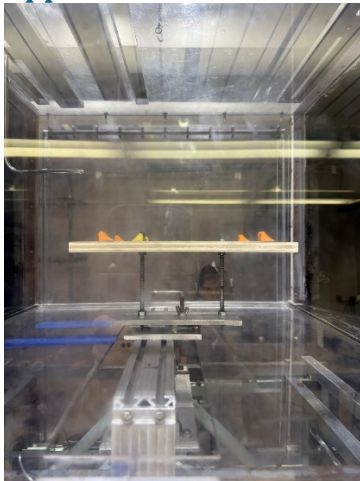
xticks(1:3);
xticklabels({'Open-bed', 'Flat-bed', 'Optimized-bed'});
ylabel('Net Drag (N)');
title('Drag Comparison (Mounting Drag Subtracted)');
grid on;

% table
% percentage drag reduction for flat & optimized bed
flat_pct = (open_mean - flat_mean) / (open_mean-mount_mean) * 100;
opt_pct = (open_mean - opt_mean) / (open_mean-mount_mean) * 100;

Configuration = {'Mounting'; 'Open-bed'; 'Flat-bed'; 'Optimized-bed'};
Net_Drag = [mount_mean; open_mean-mount_mean; flat_mean-mount_mean; opt_mean-mount_mean];
Percent_Lower_vs_Open = [NaN; 0; flat_pct; opt_pct];

T = table(Configuration, Net_Drag, Percent_Lower_vs_Open);
disp(T);
```

Appendix F: Additional figures



Mounting apparatus alone in the wind tunnel.