Results Report

Aluminum Association Aluminum Vehicle Structure - Manufacturing and Lifecycle Cost Analysis

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Overview

IBIS Associates, an independent consulting firm specializing in the techno-economic analysis of materials and manufacturing technologies, has been engaged to assess the manufacturing and lifecycle economics of lightweight aluminum automotive structures. This analysis seeks to quantify the commercial production economics of proven aluminum designs and production techniques previously developed by automotive OEMs and compare these results with incumbent materials and practices.

IBIS, with significant experience in techno-economic comparisons of alternative automotive structures, has developed and applied Technical Cost Models of several manufacturing alternatives for automotive structures, powertrain, and chassis systems. From these tools, analyses are conducted to explore the cost breakdown and sensitivity to important design and process assumptions. Insight is gained into individual component piece cost, assembled structure piece cost, yearly direct manufacturing cost, and total fixed capital investment as well as the mass and cost impact on secondary system savings and lifecycle usage costs.

Objectives

The project scope involves developing a baseline aluminum to steel design comparison, taken from successfully demonstrated aluminum structure programs. Using IBIS cost models, the respective direct manufacturing costs of each structure are then evaluated. The resulting cost and masses are then used in a vehicle system model to assess the impact of secondary mass and cost savings and the differential in lifecycle usage costs. Specifically, this analysis addresses the following questions:

- **What are the comparative direct manufacturing costs of steel and aluminum usage?**
- **In addition to material price differences, what is the impact of aluminum usage on fabrication and assembly costs?**
- **What are impacts on other vehicle systems stemming from structure mass reduction?**
- **What is the magnitude of aluminum usage cost premiums and savings relative to the entire vehicle totals?**
- **How do mass and production cost differences relate to overall operation and lifecycle cost impact to the consumer?**

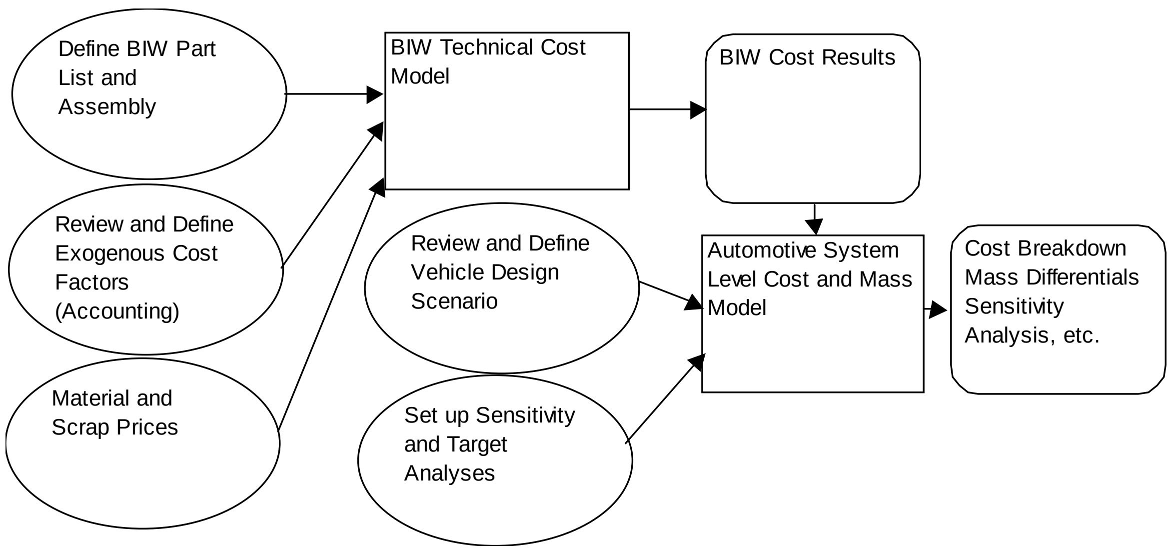
Workplan

- Project Design and Study Definition
  - Definition of baseline scenarios
  - Preliminary definition of aluminum design
    - *Fabrication technologies*
    - *Body components to be considered*
    - *Production scenarios*
- Model structure development
  - Integration of existing manufacturing model structures
  - System requirement relationships
  - Additional data collection
  - Cost model refinement
- Presentation and review of preliminary results
- Verification of scenario and process assumptions with **AA team** data
- Integration of alternative design data from **AA team**
- Refinement of the analysis
- Presentation of final results

Methodology

In order to address the stated objectives of the program, Technical Cost Models (TCMs) of the manufacturing and assembly processes were employed. In Technical Cost Modeling, as employed by IBIS Associates, process costs are addressed by dynamic economic simulations of manufacturing processes. In this approach, the process starts with a user-defined manufacturing scenario in terms of component geometry, production volume, and accounting assumptions. The models then assess equipment, tooling, and building capital requirements based on definitions of individual components and process parameters. Variable costs in terms of material, labor, and energy are calculated based on component geometry, scrap and yield losses, process rates, and equipment usage. Manufacturing overhead labor, maintenance cost, and the interest cost of investments and working capital are also included. This dynamic approach is particularly useful in exploring cost sensitivities, such as production rate, yield, as well as understanding the equipment and tooling implications of material and design differences.

Two separate Technical Cost Models are used for this analysis. The first is a Body-In-White (BIW) manufacturing model used to evaluate the direct manufacturing cost for the stamping, casting, machining, heat treating, and assembly of all the individual components of the steel and aluminum body structures and closure panels. The second model evaluates entire vehicle system composition and lifecycle cost elements, in order to explore the potential impact of weight savings on specific vehicle subsystems and downstream usage costs. The flow of data is outlined in the following figure.



Comparison of Vehicle Architectures

Data Sources

In order to develop a reasonable comparison of BIW architectures, the Aluminum Association team management made the decision to base the aluminum structure design on a previously demonstrated platform. Several iterations of aluminum body structures have been examined in the past decade from which detailed design and engineering data was available. While there have been improvements in the state of the art for both material systems in recent years, the robustness of design and availability of detailed data made these programs desirable as the basis for the analysis. Specifically, the P2000 design was targeted as the platform basis.

With the approval of Ford, Novelis provided design data in terms of BIW structure and closure set mass specifications and assembly procedures for the Ford AIV. Also provided was a list of aluminum and steel stampings for the P2000 program and the Contour structure from which it was derived, along with material designations, blank sizes and component mass estimates. This data was compared with detailed component data previously collected by IBIS for the DN5 platform and the Ford AIV.

BIW Structure Design Parameters

Vehicle	90s Taurus	DN5	AIV	P2000	Contour
Mass (lbs)					
Structure	596	491	320	319	595
Closures	222	142	117	114	186
total	818	633	437	433	781

Aluminum Scenario

From available PNGV documentation on the P2000 program, a detailed list of individual components for the body structure was developed. The source data included program part numbers, part names, weight per part, weight per vehicle, material designation, and thickness, as well as the equivalent part data on the Contour basis parts. This data was then organized by materials, manufacturing process, and mass, for inputs into the BIW production cost model. The P2000 part list defines 182 aluminum stampings, six castings, and 55 steel stampings carried over from the Contour baseline. In addition to these there were some small stampings and brackets weighing 18 kg which were included in the analysis. Panel closure masses, including hinges, were also detailed in PNGV data.

- **P2000 Structure**
  - 182 Al stampings, 110 kg
  - 6 Al Castings, 8 kg
  - 55 steel stampings, 7 kg
  - and miscellaneous (brackets, etc), 18kg

Steel Baseline Equivalent

The Contour equivalent parts list, along with the equivalent miscellaneous stampings and bracketry were used to define the total steel baseline equivalent. As in the aluminum scenario, additional small stampings and brackets were included in the analysis. In the resulting scenario part lists, identical "carry-over" parts were identified, as well as those that had to be multiple parts for aluminum stamping.

- **Contour-based Steel equivalent**
  - 244 steel stampings plus miscellaneous, 272 kg

Target Mass for Structures	Al Mass (lbs)	Steel Mass (lbs)	Al Mass Savings
BIW Structure	315	595	47%

Target Mass for Closures	Al Mass (lbs)	Steel Mass (lbs)	Al Mass Savings
Hood	17	30.9	45%
Decklid	13	24	45%
Front Door	40	62.2	35%
Rear Door	38	59.1	35%
Fenders	5	9.6	50%
	114	186	

Material Pricing

Given the uncertainty of future aluminum pricing for high volume supply, the following strategy was adopted. In the FreedomCar proposal, references were made to current aluminum pricing around $1.75/lb, with a future volume price goal of around $1.25. In the cost modeling presented here, $1.50 was adopted as a mid-range baseline. The total BIW cost was then analyzed at the high and low end of the $1.25-$1.75/lb range to explore the impact this magnitude of difference makes.

- **Aluminum sheet price based on FreedomCar proposal references:**
  - $1.75/lb as current
  - $1.25/lb as future target
  - $1.50/lb as middle baseline for analysis

While steel sheet pricing can also depend on contract timing and market fluctuations, the industry standard of $0.35 was used for mild steel.

- **Steel price based on numerous datapoints**
  - $0.35/lb mild
  - $0.37/lb HSLA
  - $0.10/lb scrap (WSJ 9/27/05)

The table below shows the analysis material assumptions for the various materials and grades examined in terms of price per kilogram.

MATERIAL SPECIFICATIONS	Description	Price ($/kg)	Scrap ($/kg)	Density (g/cc)
1	6xxx Outer	$3.31	$1.59	2.70
2	6xxx Inner & Struct	$3.31	$1.59	2.70
3	5xxx Structure & Reinf	$3.31	$1.59	2.70
4	6xxx Casting	$2.21	$1.10	2.70
5	Steel Mild Structural	$0.77	$0.22	7.85
6	Steel Ext. App.	$0.77	$0.22	7.85
7	HSLA	$0.82	$0.22	7.85
8				

Manufacturing Cost Analysis

With the target scenarios for comparison defined as discussed in the previous section, specialized cost models for BIW structure, closure panels, and assembly were employed. These models were tailored for this analysis to provide the ability to examine the costs of each of the hundreds of components involved. As described in the methodology section, the individual piece cost as well as the total cost of the BIW is assessed in terms of fixed and variable cost elements. The following section describes the approach to modeling the target structures as well as the important differences based on materials and design.

Process Assumptions

Component Fabrication

The primary manufacturing process involved in both the aluminum and steel structure scenarios is press line and tandem sheet stamping. Required press tonnage is assigned to each component based on material, area, and thickness. The number of presses in a press line required to blank, form, and trim each part is also assigned based on material, part design, and complexity. Equipment cost, cycle time, power, and floorspace requirements are functions of the press tonnage. The number of press operators and tool costs are functions of the number of presses required to form each part. Scrap rates were both calculated directly from blank size or applied as facility averages depending on data availability. The steel structure used an average of 45% engineered scrap while the aluminum average was slightly higher, at 50% because of considerations for draw and springback.

For each of the cast components, secondary machining and heat treatment operations were addressed.

Structure Assembly

For both steel and aluminum, spot welding is employed in BIW assembly. The model addresses manual and automated subassembly, as well as manual and automated final assembly. In subassembly spot welding, two or more parts are placed in a fixture. Resistance spot welding guns close on the part, securing it, and apply the weld. For automated operations, closely spaced weld robots and positioning fixtures are used that dimensionally stabilize and rapidly apply a large number welds. Final assembly applies welds for reinforcement in a series of stations, but in complex fixtures.

Aluminum spot welding process is similar to steel but with a few differences. More current is required for aluminum, resulting in higher energy costs. Heavier transformers for the welding guns are therefore needed, which in turn gives rise to the need for heavier payload robots for aluminum. In addition, full wave DC rectifiers are used for aluminum, while steel can be welded with AC. Finally, the wear of the electrode tips is much greater for aluminum than steel. More expensive tip cooling systems are used to extend the life somewhat, with the net effect of a much higher consumable cost per weld ($0.015/weld for aluminum vs. $0.005/weld for steel).

While the traditional steel structure assembly is spot welded, the P2000 and AIV programs specified weld bonding and several other joining methods. The Ford AIV Assembly Manual was made available to IBIS, which was then distilled for the required assembly process descriptions for the modeling exercise. The relevant operation parameters needed for modeling the operations are listed in the table below.

AIV Assembly Operations

	SUBASSEMBLIES	Spot Welds (# / SA)	Seam Welds (cm / SA)	Adhesive Length (cm / SA)	Comments
1	Rear Floor Crossmember Assembly	120	2	137.5	
2	Rear Rail and Ladder Assembly	180	0	290	10 rivets
3	Rear Floor Pan Assembly	147	0	920	8 rivets
4	Front Floor Pan Assembly	101	0	820	28 rivets
5	Crossmember At Dash Assembly	40	0	1650	
6	Dash Panel Assembly	40	0	80	
7	Apron and Front Sidemember Assemb	300	0	945	
8	Radiator Support Assembly	50	0	257.5	
9	Front Structure Assembly	545	0	3157.5	4 rivets
10	Cowl Assembly	144	0	390	
11	Package Tray Assembly	42	0	260	
12	Lower Back Panel Assembly	30	0	190	
13	Bodyside Assembly	1208	0	4899	6 fusion welds, 1 drill, nut/bolt
14	Framing	804		2010	8 rivets

Adhesive used in the weld bonding is assumed to be a product similar to the AV4600 employed in adhesive bonding of the Jaguar XJ, reported to cost around $45/lb. With an applied bead diameter of 3mm, the resulting applied adhesive cost is in the $0.13-$0.15/ft range.

For the aluminum scenario, the individual assembly operations were modeled as described above. In the steel case the spot welds were assigned to manual subassembly, automated subassembly, manual final assembly and automated final assembly in the percentages of 35%, 40%, 4% and 21%, respectively. The aluminum weld bonding schedule above calls for 3700 spots while the steel structure used 4000 spot welds.

Cost Analysis Results

The cost model results of direct manufacturing costs for the steel and aluminum BIW scenarios (annual production of 250,000) are presented in the following tables.

Steel BIW

Structure

AUTO BIW TCM: COST SUMMARY OUTPUTS - FORD CONTOUR				
IBIS Associates, Inc., Waltham, Massachusetts USA		Copyright (c) 2005 v1.0		
STRUCTURE FABRICATION	per unit	per year	percent	invest ($M)
Material Cost	$340.13	$85,031,958	32.0%	
Labor Cost	$138.40	$34,600,953	13.0%	
Utility Cost	$2.92	$729,966	0.3%	
Equipment Cost	$152.77	$38,192,380	14.4%	$318
Tooling Cost	$174.88	$43,721,081	16.5%	$175
Building Cost	$9.25	$2,312,691	0.9%	$48
Maintenance Cost	$33.69	$8,422,615	3.2%	
Overhead Labor Cost	$51.85	$12,961,615	4.9%	
Interest Cost	$158.34	$39,584,757	14.9%	
STRUCTURE FABRICATION COST	$1,062.23	$265,558,017	100%	$541

Panels

AUTO BIW TCM: COST SUMMARY OUTPUTS - FORD CONTOUR				
IBIS Associates, Inc., Waltham, Massachusetts USA		Copyright (c) 2005 v1.0		
PANEL FABRICATION	per unit	per year	percent	invest ($M)
Material Cost	$102.02	$25,504,488	44.4%	
Labor Cost	$32.87	$8,218,297	14.3%	
Utility Cost	$0.35	$87,194	0.2%	
Equipment Cost	$17.03	$4,257,414	7.4%	$46
Tooling Cost	$35.37	$8,842,158	15.4%	$35
Building Cost	$1.23	$306,582	0.5%	$8
Maintenance Cost	$5.36	$1,340,615	2.3%	
Overhead Labor Cost	$11.56	$2,890,228	5.0%	
Interest Cost	$23.95	$5,986,789	10.4%	
PANEL FABRICATION COST	$229.74	$57,433,765	100%	$90

Assembly

AUTO BIW TCM: COST SUMMARY OUTPUTS - FORD CONTOUR				
IBIS Associates, Inc., Waltham, Massachusetts USA		Copyright (c) 2005 v1.0		
ASSEMBLY	per unit	per year	percent	invest ($M)
Material Cost	$20.00	$5,000,000	5.8%	
Labor Cost	$165.53	$41,382,000	48.3%	
Utility Cost	$10.24	$2,559,600	3.0%	
Equipment Cost	$51.83	$12,957,349	15.1%	$104
Tooling Cost	$22.10	$5,525,000	6.5%	$22
Building Cost	$5.13	$1,283,200	1.5%	$26
Maintenance Cost	$7.91	$1,976,555	2.3%	
Overhead Labor Cost	$12.24	$3,060,000	3.6%	
Interest Cost	$47.64	$11,909,320	13.9%	
ASSEMBLY COST	$342.61	$85,653,023	100%	$151

Steel Summary

AUTO BIW TCM: COST SUMMARY - FORD CONTOUR IBIS Associates, Inc., Waltham, Massachusetts USA Copyright (c) 2005 v1.0				
	Total	**Structure**	**Panel**	**Assembly**
Material	$462	$340	$102	$20
Dir/Ovrhd Labor	$412	$190	$44	$178
Equipment	$222	$153	$17	$52
Tooling	$232	$175	$35	$22
Utility/Building/Maintenance	$76	$46	$7	$23
Interest Cost	$230	$158	$24	$48
TOTAL PIECE COST	**$1,635**	$1,062	$230	$343
Equipment Investment ($M)	$468.1	$318.2	$46.3	$103.7
Tooling Investment ($M)	$232.4	$174.9	$35.4	$22.1
Building Investment ($M)	$81.1	$47.5	$7.9	$25.7
TOTAL INVESTMENT	**$781.6**	$540.6	$89.6	$151.4
Mass (kg)	**356**	272	84	0
Piece Count	**320**	306	14	n/a
Annual Production Volume	250	000/year		

Aluminum BIW

Structure

AUTO BIW TCM: COST SUMMARY OUTPUTS - FORD P2000 IBIS Associates, Inc., Waltham, Massachusetts USA Copyright (c) 2005 v1.0				
STRUCTURE FABRICATION	per unit	per year	percent	invest ($M)
Material Cost	$642.97	$160,742,795	46.4%	
Labor Cost	$148.30	$37,075,333	10.7%	
Utility Cost	$4.19	$1,048,579	0.3%	
Equipment Cost	$142.64	$35,661,089	10.3%	$305
Tooling Cost	$186.49	$46,623,347	13.5%	$186
Building Cost	$8.62	$2,154,431	0.6%	$46
Maintenance Cost	$33.78	$8,443,887	2.4%	
Overhead Labor Cost	$56.43	$14,106,593	4.1%	
Interest Cost	$161.09	$40,271,539	11.6%	
STRUCTURE FABRICATION COST	$1,384.51	$346,127,593	100%	$538

Panels

AUTO BIW TCM: COST SUMMARY OUTPUTS - FORD P2000				
IBIS Associates, Inc., Waltham, Massachusetts USA	Copyright (c) 2005 v1.0			
PANEL FABRICATION	per unit	per year	percent	invest ($M)
Material Cost	$246.40	$61,600,754	65.0%	
Labor Cost	$32.87	$8,218,297	8.7%	
Utility Cost	$0.35	$87,194	0.1%	
Equipment Cost	$16.99	$4,246,251	4.5%	$46
Tooling Cost	$37.05	$9,262,936	9.8%	$37
Building Cost	$1.23	$306,582	0.3%	$8
Maintenance Cost	$5.53	$1,381,577	1.5%	
Overhead Labor Cost	$11.56	$2,890,228	3.0%	
Interest Cost	$27.27	$6,816,772	7.2%	
PANEL FABRICATION COST	$379.24	$94,810,592	100%	$91

Assembly

AUTO BIW TCM: COST SUMMARY OUTPUTS - FORD P2000				
IBIS Associates, Inc., Waltham, Massachusetts USA	Copyright (c) 2005 v1.0			
ASSEMBLY	per unit	per year	percent	invest ($M)
Material Cost	$123.47	$30,868,027	28.7%	
Labor Cost	$117.22	$29,304,000	27.2%	
Utility Cost	$18.14	$4,536,000	4.2%	
Equipment Cost	$76.18	$19,045,223	17.7%	$152
Tooling Cost	$16.80	$4,200,000	3.9%	$17
Building Cost	$3.23	$806,400	0.7%	$16
Maintenance Cost	$9.62	$2,405,162	2.2%	
Overhead Labor Cost	$8.24	$2,060,000	1.9%	
Interest Cost	$57.97	$14,492,072	13.5%	
ASSEMBLY COST	$430.87	$107,716,885	100%	$185

Aluminum Summary

AUTO BIW TCM: COST SUMMARY - FORD P2000
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	Total	Structure	Panel	Assembly
Material	$1,013	$643	$246	$123
Dir/Ovrhd Labor	$375	$205	$44	$125
Equipment	$236	$143	$17	$76
Tooling	$240	$186	$37	$17
Utility/Building/Maintenance	$85	$47	$7	$31
Interest Cost	$246	$161	$27	$58
TOTAL PIECE COST	**$2,195**	$1,385	$379	$431
Equipment Investment ($M)	$503.9	$305.4	$46.2	$152.4
Tooling Investment ($M)	$240.3	$186.5	$37.1	$16.8
Building Investment ($M)	$69.6	$45.6	$7.9	$16.1
TOTAL INVESTMENT	**$813.9**	$537.5	$91.1	$185.3
Mass (kg)	**196**	143	52	1
Piece Count	**346**	332	14	n/a
Annual Production Volume	250	000/year		

Architecture Comparison – Unit Costs

AUTO BIW TECHNICAL COST MODEL: PIECE COST BREAKDOWN BY ELEMENT
IBIS Associates, Inc., Wellesley Massachusetts Copyright (c) 2005 v1.0

Annual Volume: 250,000/year

OVERALL

Case	Matl	Labor	Equip	Tool	Interest	Other	Total	Pct Base
Steel	$462	$337	$222	$232	$230	$152	**$1,635**	100%
P2000	$1,013	$298	$236	$240	$246	$161	**$2,195**	134%

STRUCTURE

Case	Matl	Labor	Equip	Tool	Interest	Other	Total	Pct Base
Steel	$340	$138	$153	$175	$158	$98	**$1,062**	100%
P2000	$643	$148	$143	$186	$161	$103	**$1,385**	130%

PANELS

Case	Matl	Labor	Equip	Tool	Interest	Other	Total	Pct Base
Steel	$102	$33	$17	$35	$24	$18	**$230**	100%
P2000	$246	$33	$17	$37	$27	$19	**$379**	165%

ASSEMBLY

Case	Matl	Labor	Equip	Tool	Interest	Other	Total	Pct Base
Steel	$20	$166	$52	$22	$48	$36	**$343**	100%
P2000	$123	$117	$76	$17	$58	$39	**$431**	126%

Architecture Comparison – Totals, Investment, and Mass

AUTO BIW TECHNICAL COST MODEL: OVERALL COST SUMMARY
IBIS Associates, Inc., Wellesley Massachusetts Copyright (c) 2005 v1.0
Annual Volume: 250,000/year

Product Type **Auto BIW**

Case	Structure	Panels	Assembly	**Total**	Pct Base	Invest ($M)	Mass (kg)	Piece Count
Steel	$1,062	$230	$343	**$1,635**	100%	$782	356	320
P2000	$1,385	$379	$431	**$2,195**	134%	$814	195	346

AUTO BIW TECHNICAL COST MODEL INVEST COST BREAKDOWN BY ELEMENT
IBIS Associates, Inc., Wellesley Massachusetts Copyright (c) 2005 v1.0
Annual Volume: 250,000/year

OVERALL

Case	Structure Inv ($M)	Panels Inv ($M)	Assembly Inv ($M)	**Total Inv ($M)**	Pct Base	Equip Inv ($M)	Tooling Inv ($M)	Building Inv ($M)
Steel	$541	$90	$151	**$782**	100%	$468	$232	$81
P2000	$538	$91	$185	**$814**	104%	$504	$240	$70

AUTO BIW TECHNICAL COST MODEL PIECE COUNT AND MASS SUMMARY
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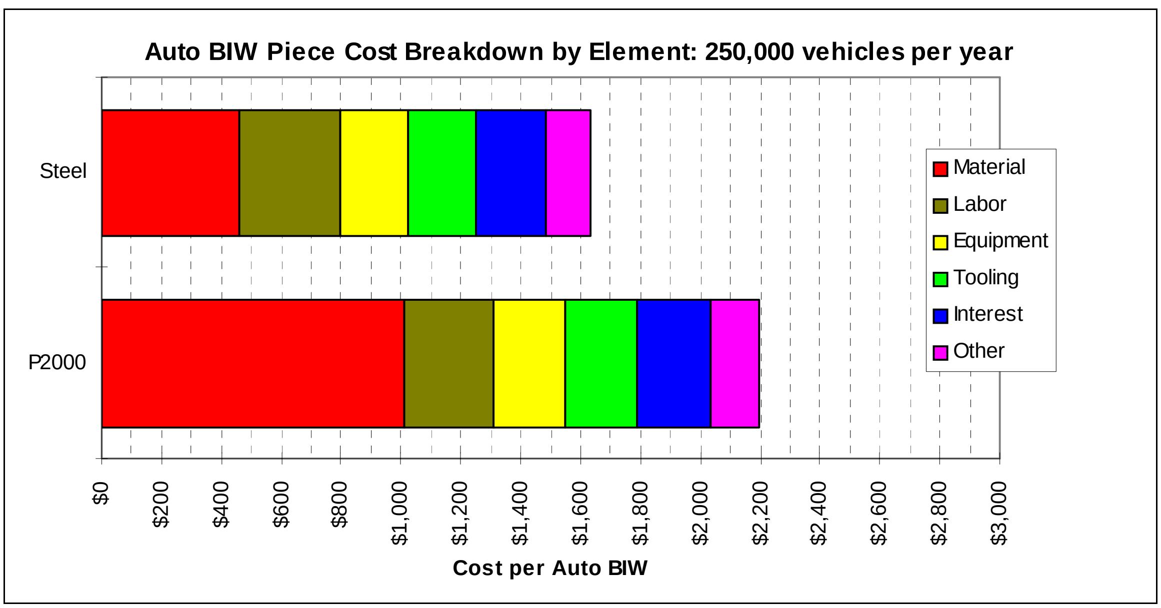
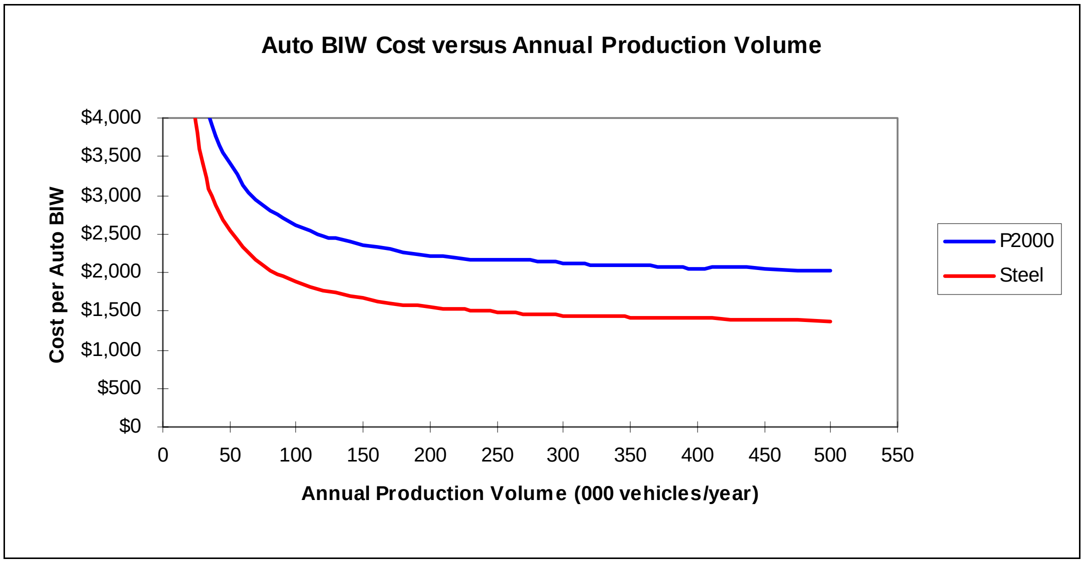
Case	Structure/ Assembly Mass (kg)	Panel Mass (kg)	**Total Mass (kg)**	Pct Base	Structure Count	Panel Count	**Total Count**	Pct Base
Steel	272	84	**356**	100%	306	14	**320**	100%
P2000	143	52	**195**	55%	332	14	**346**	108%

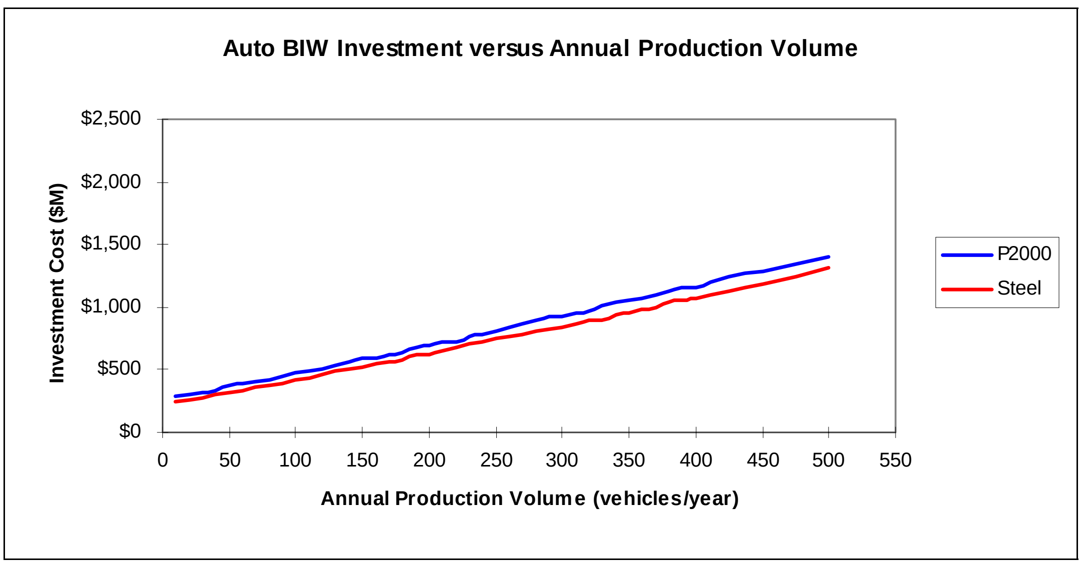


Sensitivity Analysis

Production Volume

In the following charts, the effect on total BIW manufacturing cost and capital investment of changes in annual production volume is shown. Because the bulk of capital investment costs are in presses and tools that are nearly the same for both materials, the part cost sensitivity curve for both materials is the same shape, with an offset primarily due to the material cost difference.





Material Price

OVERALL	$1.25/lb Al per unit	$1.50/lb Al per unit	$1.75/lb/Al per unit
Material Cost	$867.80	$1,012.85	$1,157.89
Labor Cost	$298.39	$298.39	$298.39
Utility Cost	$22.69	$22.69	$22.69
Equipment Cost	$235.81	$235.81	$235.81
Tooling Cost	$240.35	$240.35	$240.35
Building Cost	$13.07	$13.07	$13.07
Maintenance Cost	$48.92	$48.92	$48.92
Overhead Labor Cost	$76.23	$76.23	$76.23
Interest Cost	$243.41	$246.32	$249.23
OVERALL COST	$2,046.67	$2,194.62	$2,342.58

In order to explore the impact of changing material price assumptions on the cost of the aluminum structure, the TCM was used to determine BIW costs at different aluminum sheet prices. The cost of casting ingot was also varied over the same +/-16.7%. The resulting change in total costs makes the cost premium over steel (the steel price has been kept constant) for the aluminum structure 43% at the high end of material cost, 25% at the low end, and 34% for the mid-range assumption.

Vehicle Design and Lifecycle Cost Analysis

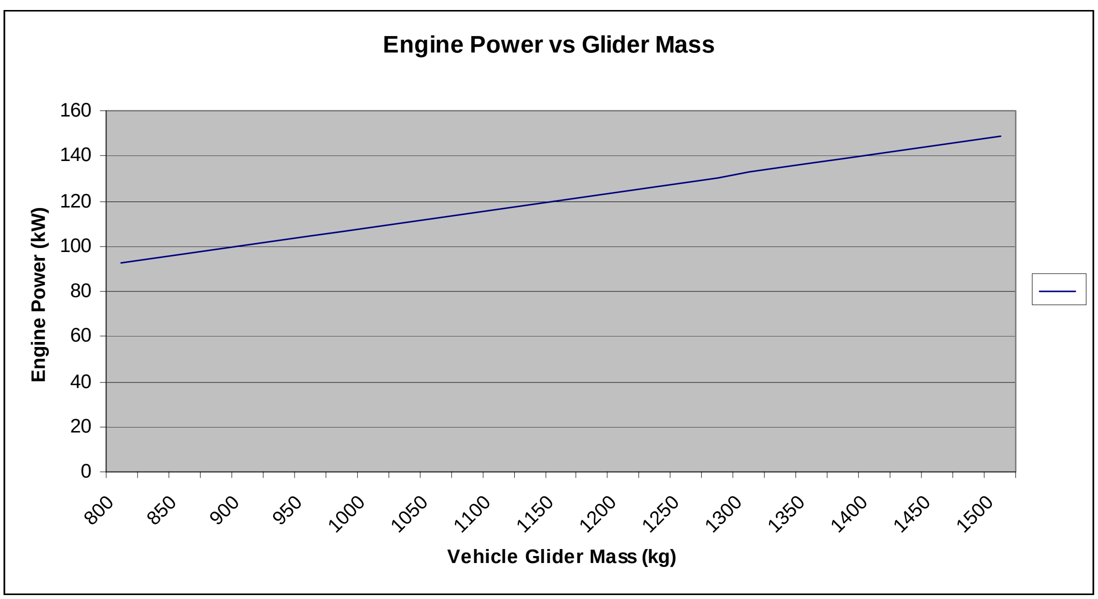
Overview

The BIW mass and cost elements are then used in simulating the system mass and cost relationships for a recent model midsize passenger car in the Vehicle System Cost and Lifecycle Model. After the initial vehicle description in terms of system definitions and lifecycle parameters, the model calculates the functionally equivalent power requirements and makes estimates of the differential mass and cost impact on vehicle mass and power dependent subsystems.

In addition to the BIW structure and body panels, the aluminum vehicle scenario employs aluminum bumpers, engine cradle, and wheels, while these are all steel on the steel vehicle scenario.

Structure Mass Impact on Other Vehicle Systems

Performance parameters in terms of acceleration are held constant, as are frontal area, coefficient of drag and rolling resistance. This means horsepower can be reduced for lighter vehicles, with the resulting reduction in engine cost and mass, as well as impacting other subsystems. An alternative assumption would be to hold horsepower and engine size constant, resulting in better power-to-mass performance, but foregoing the secondary weight and fuel savings.



The resulting reduced engine power and vehicle mass also reduces the mass and material cost of the suspension, braking, and steering systems as shown in the detailed results below.

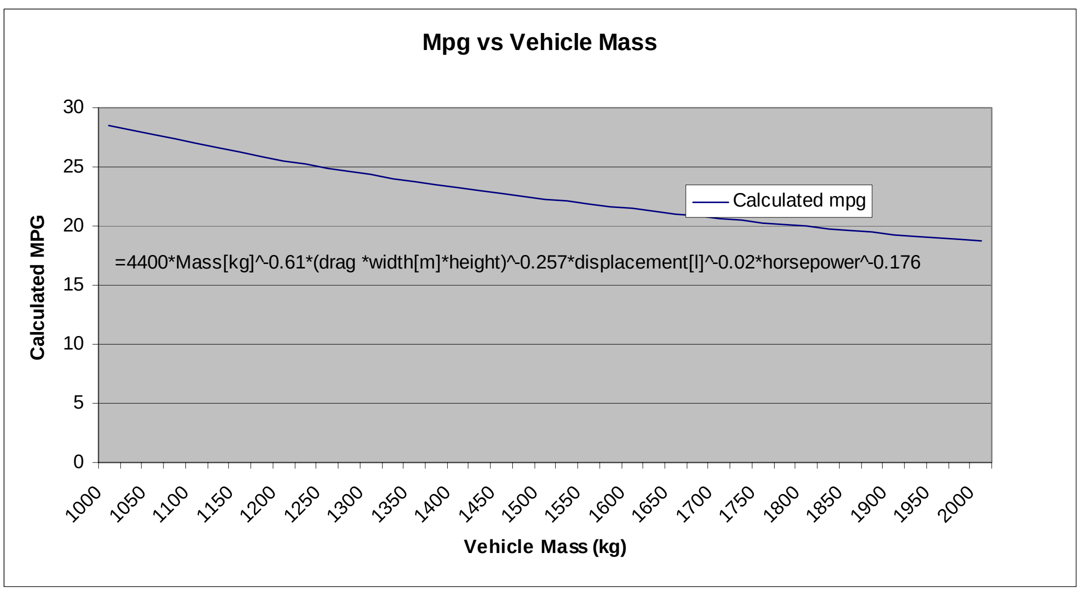
Operation and Lifecycle Elements

In addition to the secondary mass savings on the vehicle, the Vehicle System model addresses operation costs over the useful life of the vehicle. These costs are incurred on a monthly or annual basis and are discounted (7% APR) to a net present value (PV) for the sake of comparison with manufacturing costs.

Mass-based Lifecycle Elements

Fuel price is a major factor of lifecycle costs and fuel prices have been volatile in recent years. For the sake of the analysis a constant $2.50/gallon was assumed. Sensitivity analysis and attention to this assumption may be warranted based on recent fuel market behavior. 10,000 miles/year driven and a 12-year life are assumed.

Fuel economy is calculated as a function of vehicle mass, drag, engine power, and engine displacement from an IBIS algorithm. The algorithm was developed from regression of published data on vehicle fuel economy, engine power, frontal area, and drag or vehicles in the North American market. For the target platform, the mass differential and power demand the algorithm yielded a 14.9% fuel economy improvement for aluminum vehicle over steel vehicle.



Other Lifecycle Elements

The financing cost and local fees are functions of the purchase price of the car. Insurance, maintenance, and repair are assumed to be constant for the target scenarios.

Finally, disposal cost is a function of the residual scrap value of the recovered materials. There is a well developed industry for removing re-usable and sellable components, shredding vehicle hulks, separating ferrous and non-ferrous metals, and landfilling the remaining material. For this analysis, end-of-life scrap values of $0.40/lb for aluminum and $0.06/lb for steel were used to assess the inherent material value of the structure at the time of disposal. In reality, it is unclear who, along the value chain, the beneficiary of increased scrap value would be.

LCA Results

Note that in the system summary results, the BIW cost category reflects body structure and assembly costs together, while closure panels are listed separately.

VEHICLE LIFECYCLE COST SUMMARY

	Baseline Steel			Baseline Aluminum		
	Gasoline ICE Midsize Steel Unibody			Gasoline ICE Midsize Aluminum Unibody		
	System Name	Mass (kg)	Cost ($)	System Name	Mass (kg)	Cost ($)
TOTAL MANUFACTURING		**1,564**	**$14,871**		**1,288**	**$14,974**
RETAIL PRICE			$23,819			$23,964
TOTAL OWNERSHIP			$51,520			$50,344
Powertrain		701	$6,908		617	$6,445
Engine	V-6 DOHC CI/CI	257	$2,535	V-6 DOHC CI/CI	219	$2,160
Energy Storage	Lead-Acid, standard	18	$53	Lead-Acid, standard	16	$45
Fuel System	Gasoline , 18.5 gal	89	$388	Gasoline, 17 gal	83	$376
Transmission	Automatic, 4 speed car	79	$1,177	Automatic, 4 speed car	67	$1,151
P/T Thermal	Generic car	29	$150	Generic car	29	$150
Driveshaft/Diff/Axle	generic	110	$1,397	generic	99	$1,304
Cradle	Sheet steel	36	$83	Extruded aluminum	21	$134
Exhaust System	generic	48	$300	generic	48	$300
Oil and Grease	generic	15	$25	generic	15	$25
Powertrain Electronics	generic	10	$400	generic	10	$400
Emission Control Electronics	generic	10	$400	generic	10	$400
Body		433	$2,665		270	$3,295
Body-in-White	Midsize Steel Unibody	272	$1,405	Midsize Aluminum Unibody	145	$1,816
Panels	Stamped Steel Mid	84	$230	Stamped Aluminum Mid	52	$379
Front/Rear Bumpers	Sheet steel	9	$30	Extruded aluminum	6	$50
Glass	Conventional, 4mm	37	$250	Conventional, 4mm	37	$250
Paint	Solventborne, avg color	11	$450	Solvb on Al, avg color	11	$495
Exterior Trim	generic	9	$50	generic	9	$50
Body Hardware	generic	9	$226	generic	9	$226
Body Sealers and Deadeners	generic	2	$24	generic	2	$29
Chassis		207	$1,537		178	$1,473
Corner Suspension	generic	48	$220	generic	40	$198
Braking System	ABS	49	$420	ABS	41	$377
Wheels and Tires	generic steel	82	$317	aluminum 15"	76	$407
Steering System	generic	28	$580	generic	22	$491
Interior		156	$2,156		156	$2,156
Instrument Panel	generic	25	$110	generic	25	$110
Trim and Insulation	generic	23	$429	generic	23	$429
Door Modules	generic	26	$220	generic	26	$220
Seating and Restraints	generic	62	$1,122	generic	62	$1,122
HVAC	generic	21	$275	generic	21	$275
Electrical		27	$1,000		27	$1,000
Interior Electrical	generic	9	$400	generic	9	$400
Chassis Electrical	generic	9	$400	generic	9	$400
Exterior Electrical	generic	9	$200	generic	9	$200
Final Assembly		40	$605		40	$605
Interior to Body	World Class Interior	5	$140	World Class Interior	5	$140
Chassis to Body	World Class Chassis	10	$90	World Class Chassis	10	$90
Powertrain to Body	World Class Powertrain	10	$90	World Class Powertrain	10	$90
Electronics to Body	World Class Electronics	5	$80	World Class Electronics	5	$80
Other Systems to Body	Vorld Class Other Systems	10	$205	World Class Other Systems	10	$205
Overhead		0	$8,948		0	$8,990
OEM Overhead	Baseline	0	$3,000	Baseline	0	$3,000
Dealer Cost	Function of Mfg. Cost	0	$5,948	Function of Mfg. Cost	0	$5,990
Operation			$27,700			$26,380
Financing PV Cost	Baseline		$18,819	Baseline		$18,964
Insurance PV Cost	Baseline		$12,050	Baseline		$12,050
Local Fees PV Cost	Baseline		$1,928	Baseline		$1,936
Fuel PV Cost	Baseline		$9,342	Baseline		$8,071
Maintenance PV Cost	Baseline		$3,591	Baseline		$3,591
Repair PV Cost	Baseline		$810	Baseline		$810
Disposal PV Cost	Baseline		-$21	Baseline		-$77
	0					

Summary of Most Significant Differentials

The following table highlights the specific mass reductions created by the reduced body mass. This table also shows selected data from the overall summary above, focussing on the mass and cost differentials. The mass savings in body structure engender reduced power requirements meaning a smaller, less expensive engine. Secondary mass savings in chassis components are also shown. The lifetime fuel cost is shown as a present value. Finally, the differential manufacturing, retail, and total ownership costs are presented.

	Baseline Steel		Baseline Aluminum		Differentials			
	Mass (kg)	Cost ($)	Mass (kg)	Cost ($)	Mass (kg)	Cost ($)	Mass (%)	Cost (%)
Body	433	$2,665	270	$3,295	163	-$630	37.58%	-23.63%
Engine	257	$2,535	219	$2,160	38	$375	14.78%	14.78%
Energy Storage	18	$53	16	$45	3	$8	14.78%	14.78%
Transmission	79	$1,177	67	$1,151	12	$26	14.78%	2.22%
Driveshaft/Diff/Axle	110	$1,397	99	$1,304	11	$93	9.59%	0.00%
Cradle	36	$83	21	$134	15	-$51	41.70%	-60.75%
Corner Suspension	48	$220	40	$198	8	$22	15.96%	10.16%
Braking System	49	$420	41	$377	8	$43	16.37%	10.13%
Steering System	28	$580	22	$491	7	$89	23.45%	15.36%
Fuel PV Cost	0	$9,342	0	$8,071	0	$1,272	0.00%	13.61%
TOTAL MANUFACTURING	1,564	$14,871	1,288	$14,974	275	-$103	17.61%	-0.69%
RETAIL PRICE	0	$23,819	0	$23,964	0	-$144	0.00%	-0.61%
TOTAL OWNERSHIP	0	$51,520	0	$50,344	0	$1,176	0.00%	2.28%

Conclusions

While the increase in cost of an aluminum BIW over steel is significant in relation to the cost of the structure itself, the differential in terms of the overall vehicle manufacturing cost is much less. When the systemic impact of aluminum structure mass savings on weight and cost reduction of powertrain and chassis systems is taken into account, the cost premium can be reduced to a very small percentage of the direct manufacturing costs and of selling price. Furthermore, when the fuel savings benefits of reduced mass of lightweight aluminum structures are taken into account, the total lifetime usage costs can approach cost parity or even a net benefit relative to conventional vehicle construction.

	Baseline Steel		**Baseline Aluminum**	
	Mass (kg)	Cost ($)	Mass (kg)	Cost ($)
BIW Cost (w closures)	356	1635	197	2,195
Total Mfg Cost	1,564	$14,871	1,288	$14,974
	Baseline Steel		**Baseline Aluminum**	
Calc avg mpg	21.7		25.1	
Only Structure and Closure Differences				
Cost of mass savings (BIW only) ($/kg)				$3.51
Secondary Mass Savings, but no sec cost savings				
Cost of mass savings (vehicle) ($/kg)				$2.03
Cost of mpg improvement ($/mpg)				$163.67
Secondary Mass and Cost Savings				
Cost of mass savings (vehicle) ($/kg)				$0.37
Cost of mpg improvement ($/mpg)				$30.09

In the summary table above, the first line compares the mass and cost of the aluminum and steel BIW structures including closures and assembly. The second line presents the analysis results of the total vehicle mass and direct manufacturing cost of each material system. Below that is presented the calculated fuel economy in miles per gallon (mpg) for each scenario's calculated mass and power.

Below the fuel economy is the cost of mass savings for BIW only, i.e. without taking into account neither the secondary mass savings (reduced engine size, transmission, driveline, cradle, suspension, braking, and steering) nor secondary cost savings. Below that is the cost of mass savings and cost of fuel economy improvement taking secondary mass savings into account but not including the secondary cost savings. Lastly, the cost of mass savings and cost of fuel economy improvement taking into account the secondary mass and secondary cost savings.

Acknowledgments

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Appendix I: Design Details

Source: Novelis

P2000 Parts List **BIW Mass (incl Roof, Qpanel):** **lbs**

#	STRUCTURE FABRICATION	Oride Mass (lbs/pc)	Piece Count	Material	Wall Thick (mm)	Blank Size (in^2)	Blanks / Sheet	Total Mass (kg/pc * pcs)
1	Reinf Front BPR Lower	3.60	1	NG5754-0	1.60	1680.00		1.63
2	MBR Body Front Cross Upper	1.20	1	AA5754-0	1.00	2016.00		0.54
3	Reinf Front Cross Member Upper	1.20	1	AA5754-0	1.00	2016.00		0.54
4	Reinf Headlamp Mounting Panel	0.50	2	AA5754-0	1.00	1872.00		0.45
5	Filler Front Bumper Lower	3.60	1	NG5754-0	1.60	1080.00		1.63
6	Spacer Battery Support	0.20	1	AA5754-0	2.00	60.00		0.09
7	Support Battery Tray Front	0.80	1	NG5754-0	2.00	384.00		0.36
8	Support Battery Tray Rear	0.60	1	NG5754-0	2.00	384.00		0.27
9	Panel Headlamp Surround	1.80	1	NG5754-0	2.00	2160.00		0.82
10	Bracket Air Bag Sensor	0.05	2	NG5754-0	2.50			0.05
11	Front Rail Inner LH	5.00	1	NG5754-0	2.00			2.27
12	Nutplate Engine Mount LH							0.00
13	Nutplate Engine Mount RH							0.00
14	Front Rail Inner RH	5.00	1	NG5754-0	2.00	4200.00		2.27
15	Front Suspension Housing	3.50	2	6000 CAST				3.18
16	Reinf Front Fender Apron RH	0.35	1	NG5754-0	1.00	576.00		0.16
17	Reinf Front Fender Apron LH	0.60	1	NG5754-0	1.00	864.00		0.27
18	Bracket Engine Mount RH	1.30	1	NG5754-0	2.00	1296.00		0.59
19	Bracket Engine Mount LH	0.70	1	NG5754-0	2.00	864.00		0.32
20	Bracket Power Str Res Susp	0.10	1	NG5754-0	3.00	140.00		0.05
21	Bracket Master Cylinder Attachment	0.15	1	Steel	2.00			0.07
22	Reinf Front Bumper Mounting	0.40	2	NG5754-0	2.00	392.00		0.36
23	Nutplate Rail Otr LH							0.00
24	Bracket Module Mounting	0.10	1	NG5754-0	2.00	1262.00		0.05
25	Bracket Elect Conctr Twr Mounting	0.02	1	AA5754-0	1.55	144.00		0.01
26	Front Rail Otr	5.80	2	NG5754-0	2.50	1800.00		5.26
27	Reinf Member Floor SD Inr Frt	2.50	2	NG5754-0	2.50	640.00		2.27
28	Reinf Member Floor SD RR	1.50	2	NG5754-0	2.50	420.00		1.36
29	Reinf Front Susp Lower Inr Bracket	0.30	2	NG5754-0	3.00	280.00		0.27
30	Bracket Brake Line Frt	0.09	4	Steel	2.00			0.16
31	Reinf Front SD Inner Member RR	0.05	2	NG5754-0	3.00	144.00		0.05
32	Filler Flr Side Inner Member RR	0.05	2	NG5754-0	1.60	400.00		0.05
33	Plate Engr Front Mounting	0.06	4	Steel	3.00			0.11
34	Reinf Front Susp Lower OTR Bracket	0.08	2	NG5754-0	2.00	144.00		0.07
35	Bracket Jacking Lift Front	0.15	2	NG5754-0	2.00	144.00		0.14
36	Reinf Hood Hinge on Body	0.30	2	NG5754-0	2.00	252.00		0.27
37	Bracket Instru Panel Mounting OTR	0.72	2	Steel	2.00			0.65
38	Front Shipping Bracket			Steel	2.25			0.00
39	Front Apron	1.50	2	AA5754-0	1.00	864.00		1.36
40	Rear Apron	1.50	2	AA5754-0	1.00	1500.00		1.36
41	Ext Front Susp Housing	0.50	2	NG5754-0	2.00	240.00		0.45
42	PLR Body Side INR	2.50	2	NG5754-0	2.00	3456.00		2.27
43	Ext Floor SD Member FT	3.50	2	Casting	3.00			3.18
44	Reinf Floor SD Member INR RR	0.07	2	AA5754-0	1.55			0.06
45	Panel Dash LHD	4.50	1	AA5754-0	1.00	3264.00		2.04
46	Member Front Cross @ Dash Panel	1.60	1	AA5754-0	1.55	800.00		0.73
47	Reinf Dash Panel @ Bracket Master C	0.22	1	NG5754-0	2.00	100.00		0.10
48	Bracket ACCL Pedal Stop LHD	0.10	1	NG5754-0	2.00	80.00		0.05
49	Panel Cowl Top OTR LHD	2.90	1	AA5754-0	1.00	2448.00		1.32
50	Cowl Top Inner LHD	1.40	1	AA5754-0	1.00	1632.00		0.64
51	Ext Dash Panel LHD	1.70	1	AA5754-0	1.00			0.77
52	Bracket Wiper Motor Mount LHD	0.16	1	NG5754-0	2.00	100.00		0.07
53	Bracket Elec Cont Processor	0.05	1	AA5754-0	1.00	64.00		0.02
54	Bracket Instru Panel CTR	0.05	1	AA5754-0	2.00	28.00		0.02
55	Bracket Cowl Top Grill Vent	0.04	2	NG5754-0	2.00	18.00		0.03
56	Bracket Wiper SPDL Support LHD	0.05	1	AA5754-0	1.55	64.00		0.02
57	Reinf Wiper Pivot Shaft Mounting	0.08	1	AA5754-0	1.55	168.00		0.04
58	Bracket Brake Pedal LHD	0.60	1	Steel	1.50			0.27
59	Bracket Cowl Top Grill Vent	0.03	1	NG5754-0	2.00	25.00		0.01
60	Ext Front Fender Apron	1.00	2	NG5754-0	1.00	1440.00		0.91
61	Bracket I/P Locator Upper		1	NG5754-0	2.00			0.00
62	Bracket I/P Locator Lower		1	NG5754-0	2.00			0.00
63	Extrusion Shotgun		2	NG5754-0	2.50	144.00		0.00
64	Reinf Rail Inner RR		2	NG5754-0	2.00	432.00		0.00
65	Panel Front Floor	18.80	1	AA5754-0	1.55	5184.00		8.53
66	Member Floor Side Center	2.55	2	NG5754-0	3.00	504.00		2.31
67	Reinforce Dash Panel Lower	0.40	1	AA5754-0	1.00	1152.00		0.18
68	Member Front Floor Cross Center	0.70	1	AA5754-0	1.55	1152.00		0.32
69	Plate Exhaust Hanger Front							0.00

70	Member Front Floor Cross	1.25	2	NG5754-0	2.50	450.00	1.13
71	Bracket Front Seat MTG Front	0.11	4	Steel	2.00		0.20
72	Member Front Floor Cross RR LWR	0.81	2	NG5754-0	2.00	360.00	0.73
73	Member Front Floor Cross OTR	0.26	2	NG5754-0	2.00	144.00	0.24
74	Reinforce Parking Brake MTF	0.65	1	NG5754-0	2.50	288.00	0.29
75	PLT Parking Brake Support	0.11	1	NG5754-0	2.00	288.00	0.05
76	Guide Parking Brake Cable Front	0.20	1	NG5754-0	2.00	98.00	0.09
77	Reinforced Anchor Front Floor	1.60	2	NG5754-0	2.00	612.00	1.45
78	Reinforcement	0.22	1	Steel	1.00		0.10
79	Gusset Floor Panel Front	0.15	2	AA5754-0	1.55	100.00	0.14
80	Reinforce Anchor Front Floor						0.00
81	Panel Rear Floor Front	3.10	1	AA5754-0	1.00	3456.00	1.41
82	Member Front Floor Cross RR	3.50	1	NG5754-0	1.60	1872.00	1.59
83	Bracket RR Seat Cushion Support	0.40	2	AA5754-0	1.00	576.00	0.36
84	Center Mount Rear Axel	2.80	1	AA5754-0	1.55	2160.00	1.27
85	Support Fuel Tank RR	0.10	2	Steel	2.00		0.09
86	Reinf Plt Master Ctrl Hole RR	0.04	1	NG5754-0	2.00		0.02
87	Reinf BDY CTR MNT For BDY HNGR	0.30	2	NG5754-0	2.50	144.00	0.27
88	Support Fuel Tank FRT INR	0.12	2	Steel			0.11
89	Reinf RR St Belt Anch	0.40	2	NG5754-0	2.50	144.00	0.36
90	Seat Belt Anchor (Inboard)	0.13	2	Steel	2.00		0.12
91	Panel RR Flr RR	5.00	1	AA5754-0	1.00	5184.00	2.27
92	Bracket RR Bumper Ext	0.20	2	NG5754-0	2.50	144.00	0.18
93	RNF Floor Side Member at BDY Tie-D	0.13	4	Steel	3.00		0.24
94	Member Floor Side RR	4.70	2	NG5754-0	2.50	2130.00	4.26
95	Reinf Floor Side RR	4.30	2	NG5754-0	3.00	2176.00	3.90
96	Bracket RR Suspension to Body	0.45	2	NG5754-0	2.00	196.00	0.41
97	Seat Belt Anchor (Outboard)	0.13	4	Steel	2.00		0.24
98	Nutplt RR Susp Tnsn Strut Att	0.06	4	Steel	2.00		0.11
99	Reinf RR Susp Brkt	0.38	2	Steel	1.50		0.34
100	Prtctr Fl Tank At St Blt Anch	0.04	2	Steel	0.80		0.04
101	RR Shipping Brkt		2	Steel	2.50		0.00
102	Exhaust Hanger	0.20	1	AA5754-0	1.00	144.00	0.09
103	Retainer RR Seat Cushion	0.02	2	NG5754-0	2.00	196.00	0.02
104	Panel RR Flr (RH)	0.75	1	AA5754-0	1.00	864.00	0.34
105	Panel RR Flr (LH)	0.75	1	AA5754-0	1.00	864.00	0.34
106	Nutplate For Shipping Brkt	0.04	2	NG5754-0	2.00	144.00	0.04
107	Panel Rear Floor Tub		1	AA5754-0	1.00		0.00
108	Filler Flr Side Inner	1.90	2	NG5754-0	2.00	864.00	1.72
109	Reinf Flr Side Inner	1.60	2	6111-T4P	2.00	912.00	1.45
110	Double Flr Side Inner	1.60	2	6111-T4P	3.00		1.45
111	Panel Bodyside Inner RR	7.00	1	NG5754-0	2.00	1920.00	3.18
112	Panel Bodyside Inner RR	7.00	1	NG5754-0	1.00	5184.00	3.18
113	Reinf RR Shock Attachment	1.90	2	6000 CAST			1.72
114	Reinf RR BPR Fascia Mntg	0.03	2	NG5754-0	2.00	64.00	0.03
115	Wheel House Inner	2.40	2	AA5754-0	1.00	3025.00	2.18
116	Panel Bodyside Outer	8.30	2	NG5754-0	1.00	8804.00	7.53
117	Panel Quarter Outer	2.00	2	6111-T4P	0.90	4320.00	1.81
118	Lock Face Quarter Panel	0.60	2	AA6111-T4	1.00	4200.00	0.54
119	Reinf Hinge Pillar	1.90	2	NG5754-0	2.00	1176.00	1.72
120	Reinf Frt Door Lower Hinge	0.11	2	NG5754-0	2.00	48.00	0.10
121	Reinf Frt Door Upper Hinge	0.17	2	NG5754-0	2.00	144.00	0.15
122	Reinf Center Pillar	3.70	2	NG5754-0	2.50	1000.00	3.36
123	Reinf Lock Pillar Ext	0.90	2	NG5754-0	2.50	432.00	0.82
124	Reinf Center Plr Lwr Hinge	0.12	2	NG5754-0	2.00	256.00	0.11
125	Reinf RR Door Check	0.07	2	NG5754-0	2.00	256.00	0.06
126	Reinf Ctr Bdy Plr Upr Hinge	0.17	2	NG5754-0	2.00	256.00	0.15
127	Reinf D Ring Frt	0.52	2	Steel	2.00		0.47
128	Retainer DR Lock Strkr RR	0.02	2	AA5754-0	1.00	64.00	0.02
129	Retainer Dr SEC Seal Frt	0.30	2	Steel	0.70		0.27
130	Reinf RR Door @ Striker	0.60	2	AA5754-0	1.00	288.00	0.54
131	Wheel House Close Out Panel	0.30	2	AA5754-0	1.00		0.27
132	Reinf Roof Side Rail	1.90	2	NG5754-0	2.00	1152.00	1.72
133	Reinf Qtr Upper		2	NG5754-0			0.00
134	Through Luggage Comp	0.30	2	AA5754-0	1.00	448.00	0.27
135	Ext Qtr Outer	0.32	2	AA5754-0	1.00	288.00	0.29
136	Ext RR Corner Lower Pillar	0.10	2	AA5754-0	1.00	128.00	0.09
137	Panel RR Light Opening	0.50	2	AA5754-0	1.00	480.00	0.45
138	Reinf D Ring RR		2	Steel	2.00		0.00
139	Retainer DR Sec Seal RR	0.30	2	Steel	0.70		0.27
140	Filler Qtr Panel RR	0.05	2	AA5754-0	1.00	144.00	0.05

141	Nutplate Decklid Hinge Mtg						0.00
142	Spcr Dr Secondary Seal						0.00
143	Brkt RR Bumper Fascia Mtg						0.00
144	Door Striker Plate						0.00
145	Pnl Roof	8.80	1	6111-T4P	0.90	4544.00	3.99
146	Pnl Windshield Header	0.80	1	AA5754-0	1.00	480.00	0.36
147	Frame Back Window Upper	0.80	1	AA5754-0	1.00	492.00	0.36
148	Bow Roof	0.60	1	AA5754-0	1.00	460.00	0.27
149	Package Tray	4.20	1	AA5754-0	1.00	2880.00	1.91
150	Package Tray Ctr Mount	2.10	1	AA5754-0	1.00	2880.00	0.95
151	Panel Upper Back	2.10	1	AA5754-0	1.00	1440.00	0.95
152	Mbr Whl Hse Inr To Pkg Tray	1.20	2	AA5754-0	1.00	480.00	1.09
153	Support - Rear Seat Back			NG5754-0	1.00		0.00
154	Brkt Package Tray Retainer	0.04	2	AA5754-0	1.00	40.00	0.04
155	Strainer	1.20	1	AA5754-0	1.55	1092.00	0.54
156	Panel Lower Back	2.50	1	AA5754-0	1.00	2448.00	1.13
157	Reinf Back Panel LWR	1.85	1	AA5754-0	1.00	1632.00	0.84
158	Reinf Lugg Comp DR LK STKR	0.30	1	NG5754-0	2.50	168.00	0.14
159	Plate RR Bumper Anchor	0.83	2	AA6111-T4	3.00	384.00	0.75
160	Sight Shield LWR Back Panel	0.71	1	AA5754-0	1.00	648.00	0.32
161	C/M @ Lower Back		1	AA5754-0	1.00		0.00
162	Brkt Mstr Cyldr Attachment	0.15	1	Steel	2.00		0.07
163	Brkt Brake Line Frt	0.09	4	Steel	2.00		0.16
164	Plate Eng Front MTG	0.06	4	Steel	3.00		0.11
165	Brkt Instru Panel Mtg OTR	0.72	2	Steel	2.00		0.65
166	Front Shipping Bracket		2	Steel	2.25		0.00
167	Brkt Brake Pedal LHD	0.60	1	Steel	2.00		0.27
168	Brkt Frt Seat MTG FRT	0.11	4	Steel	2.00		0.20
169	Reinf Flr Pan RR	0.22	1	Steel	1.00		0.10
170	Support Fuel Tank RR	0.10	2	Steel	2.00		0.09
171	Support Fuel Tank FRT INR	0.12	2	Steel	2.00		0.11
172	Seat Belt Anchor (Inboard)	0.13	2	Steel	2.00		0.12
173	RNF Flr Sd MBR at BDY Tie-DWN	0.13	4	Steel	3.00		0.24
174	Seat BLT Anchor (Outboard)	0.13	4	Steel	2.00		0.24
175	Nutplt RR Susp Tnsn Strut Att	0.06	4	Steel	2.00		0.11
176	Reinf RR Susp Brkt	0.38	2	Steel	1.50		0.34
177	Prtctr Fl Tank At St Blt Anch	0.06	2	Steel	0.80		0.05
178	RR Shipping Brkt		2	Steel	2.50		0.00
179	Reinf D Ring	0.52	2	Steel	2.00		0.47
180	Retainer DR Sec Seal	0.60	2	Steel	0.70		0.54
181	Door Striker Plate	0.17	4	Steel			0.31
182							
183							
184							
185							
							130.36
						kgs	

AUTO BIW TCM: DEFINITION INPUTS - P2000 Closures

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Case: **Ford P2000**
Code: **P2000**

#	PANEL FABRICATION	Material	Calc Mass (kg)	Surface Area (cm^2)	Blank Area (cm^2)	Wall Thick (mm)	Piece Count
1	Hood Outer	6xxx Outer	4.57	14,095	16,068	1.20	1
2	Decklid Outer	6xxx Outer	3.41	11,220	12,678	1.13	1
3	Fender	6xxx Outer	1.09	3,583	5,267	1.13	2
4	Front Door Outer	6xxx Outer	5.27	16,267	23,262	1.20	2
5	Rear Door Outer	6xxx Outer	4.76	14,687	21,590	1.20	2
6	Hood Inner	6xxx Inner & Str	3.10	11,767	15,886	0.98	1
7	Decklid Inner	6xxx Inner & Str	2.58	9,795	12,635	0.98	1
8	Front Door Inner	6xxx Inner & Str	3.89	13,723	21,408	1.05	2
9	Rear Door Inner	6xxx Inner & Str	3.95	13,000	20,411	1.13	2
10	Inner/Outer Assy	None	0.00	0	0	0.00	6

Contour Parts						
		Wall	Mass	Mass	Total Mass	Mass
	Material	Thick	/Vehicle	/Vehicle	/Vehicle	/Vehicle
		(mm)	(lbs/pc)	(kgs/pc)	(lbs)	(kgs)
80. Panel Front Floor	Mild Steel	0.70	22.71	10.30	22.71	10.29932
200. Panel Bodyside Outer	Mild Steel	0.80	18.90	8.57	37.80	17.14
110. Pnl Roof	Mild Steel	0.72	17.10	7.76	17.10	7.76
190. Panel Bodyside Inner RR	Mild Steel	0.75	15.36	6.97	13.44	6.09
131. Panel RR Flr RR	Mild Steel	0.80	11.40	5.17	11.40	5.17
1. Reinf Front BPR Low er	HSLA	2.90	11.00	4.99	11.00	4.99
17. Front Rail Inner LH	Mild Steel	1.38	9.83	4.46	9.83	4.46
20. Front Rail Inner RH	Mild Steel	1.38	9.83	4.46	9.83	4.46
32. Front Rail Otr	HSLA	1.75	9.68	4.39	19.36	8.78
53. Panel Dash LHD	Mild Steel	0.75	9.48	4.30	9.48	4.30
134. Member Floor Side RR	HSLA	1.50	7.91	3.59	15.82	7.17
6. Filler Front Bumper Low er	HSLA	2.00	7.40	3.36	7.40	3.36
60. Panel Cow l Top OTR LHD	Mild Steel	0.80	6.59	2.99	6.59	2.99
203. Reinf Hinge Pillar	Mild Steel	1.38	5.97	2.71	11.94	5.41
135. Reinf Floor Side RR	HSLA	1.38	5.65	2.56	11.30	5.12
33. Reinf Member Floor SD Inr Frt	HSLA	2.00	5.65	2.56	11.30	5.12
206. Reinf Center Pillar	HSLA	1.25	5.32	2.41	10.64	4.83
160. Package Tray	Mild Steel	0.70	5.19	2.35	5.19	2.35
194. Wheel House Inner	Mild Steel	0.75	5.18	2.35	10.36	4.70
50. Ext Floor SD Member FT	Mild Steel	1.75	5.07	2.30	10.14	4.60
170. Panel Low er Back	Mild Steel	0.70	4.96	2.25	4.96	2.25
49. PLR Body Side INR	Mild Steel	1.38	4.80	2.18	9.60	4.35
121. Member Front Floor Cross RR	HSLA	0.75	4.63	2.10	4.63	2.10
201. Panel Quarter Outer	Mild Steel	0.80	4.56	2.07	9.12	4.14
162. Panel Upper Back	Mild Steel	0.70	4.22	1.91	4.22	1.91
120. Panel Rear Floor Front	Mild Steel	1.00	4.17	1.89	4.17	1.89
62. Ext Dash Panel LHD	Mild Steel	0.80	3.89	1.76	3.89	1.76
24. Bracket Engine Mount RH	Mild Steel	2.00	3.69	1.67	3.69	1.67
171. Reinf Back Panel LWR	Mild Steel	0.75	3.67	1.66	3.67	1.66
21. Front Suspension Housing	Mild, HSL/	2.00	3.64	1.65	7.27	3.30
124. Center Mount Rear Axel	Mild Steel	0.80	3.42	1.55	3.42	1.55
180. Filler Flr Side Inner	HSLA	1.25	3.38	1.53	6.76	3.07
92. Reinforced Anchor Front Floor	HSLA	1.50	3.37	1.53	6.74	3.06
120b. Panel Rear Floor Front	Mild Steel	0.80	3.34	1.51	3.34	1.51
34. Reinf Member Floor SD RR	HSLA	2.00	3.20	1.45	6.40	2.90
21b. Front Suspension Housing	Mild, HSL/	1.75	3.18	1.44	6.37	2.89
181. Reinf Flr Side Inner	HSLA	0.75	3.13	1.42	6.26	2.84
61. Cow l Top Inner LHD	Mild Steel	0.80	3.09	1.40	3.09	1.40
46. Front Apron	Mild Steel	1.38	2.95	1.34	5.90	2.68
2. MBR Body Front Cross Upper	Mild Steel	0.85	2.91	1.32	2.91	1.32
47. Rear Apron	Mild Steel	1.38	2.85	1.29	5.70	2.59
71. Ext Front Fender Apron	Mild Steel	1.00	2.74	1.24	5.48	2.49
216. Reinf Roof Side Rail	HSLA	1.00	2.66	1.21	5.32	2.41
81. Member Floor Side Center	HSLA	1.00	2.41	1.09	4.82	2.19
54. Member Front Cross @ Dash Pa	Mild Steel	0.80	2.41	1.09	2.41	1.09
25. Bracket Engine Mount LH	Mild Steel	2.00	2.01	0.91	2.01	0.91
174. Plate RR Bumper Anchor	HSLA	2.95	1.83	0.83	3.66	1.66
191. Reinf RR Shock Attachment	Mild Steel	1.50	1.83	0.83	3.66	1.66
145. Panel RR Flr (RH)	Mild Steel	0.80	1.71	0.78	1.71	0.78
146. Panel RR Flr (LH)	Mild Steel	0.80	1.71	0.78	1.71	0.78
9. Support Battery Tray Front	Mild Steel	1.50	1.68	0.76	1.68	0.76
112. Frame Back Window Upper	Mild Steel	0.75	1.60	0.73	1.60	0.73
111. Pnl Windshield Header	Mild Steel	0.70	1.57	0.71	1.57	0.71
48. Ext Front Susp Housing	Mild Steel	2.00	1.43	0.65	2.86	1.30
85. Member Front Floor Cross	HSLA	1.00	1.41	0.64	2.82	1.28
23. Reinf Front Fender Apron LH	HSLA	0.75	1.40	0.63	1.40	0.63
202. Lock Face Quarter Panel	Mild Steel	0.80	1.37	0.62	2.74	1.24
207. Reinf Lock Pillar Ext	Mild Steel	1.25	1.30	0.59	2.60	1.18
214. Reinf RR Door @ Striker	Mild Steel	0.75	1.23	0.56	2.46	1.12
10. Support Battery Tray Rear	Mild Steel	1.50	1.21	0.55	1.21	0.55
87. Member Front Floor Cross RR L'	Mild Steel	1.00	1.14	0.52	2.28	1.03

Contour Parts (cont'd)						
		Wall	Mass	Mass	Total Mass	Mass
	Material	Thick	/Vehicle	/Vehicle	/Vehicle	/Vehicle
		(mm)	(lbs/pc)	(kgs/pc)	(lbs)	(kgs)
142. RR Shipping Brkt	Mild Steel	2.50	1.14	0.52	2.28	1.03
176. Sight Shield LWR Back Panel	Mild Steel	0.60	1.10	0.50	1.10	0.50
89. Reinforce Parking Brake MTF	Mild Steel	1.50	1.10	0.50	1.10	0.50
. Miscellaneous		1.5				
83. Member Front Floor Cross Cent	Mild Steel	0.80	1.06	0.48	1.06	0.48
113. Bow Roof	Mild Steel	0.65	1.05	0.48	1.05	0.48
221. Panel RR Light Opening	Mild Steel	0.75	1.03	0.47	2.06	0.93
222. Reinf D Ring RR	Mild Steel	2.00	0.97	0.44	1.94	0.88
123. Bracket RR Seat Cushion Supp	Mild Steel	0.70	0.93	0.42	1.86	0.84
82. Reinforce Dash Panel Lower	Mild Steel	0.75	0.83	0.38	0.83	0.38
22. Reinf Front Fender Apron RH	HSLA	0.75	0.77	0.35	0.77	0.35
136b. Bracket RR Suspension to Bo	Mild Steel	1.75	0.75	0.34	0.75	0.34
219. Ext Qtr Outer	Mild Steel	0.80	0.73	0.33	1.46	0.66
43. Bracket Instru Panel Mounting C	Mild Steel	2.00	0.72	0.33	1.44	0.65
213. Retainer DR Sec Seal	Mild Steel	0.70	0.65	0.29	1.30	0.59
42. Reinf Hood Hinge on Body	Mild Steel	1.38	0.60	0.27	1.20	0.54
45. Front Shipping Bracket	HSLA	2.25	0.60	0.27	1.20	0.54
136. Bracket RR Suspension to Boc	Mild Steel	1.38	0.59	0.27	1.18	0.54
91. Guide Parking Brake Cable Fron	Mild Steel	2.00	0.57	0.26	0.57	0.26
69. Bracket Brake Pedal LHD	Mild Steel	1.50	0.54	0.24	0.54	0.24
218. Through Luggage Comp	Mild Steel	0.75	0.53	0.24	1.06	0.48
129. Reinf RR St Belt Anch	Mild Steel	2.50	0.52	0.24	1.04	0.47
211. Reinf D Ring Frt	Mild Steel	2.00	0.52	0.24	1.04	0.47
172. Reinf Lugg Comp DR LK STKR	Mild Steel	1.50	0.51	0.23	0.51	0.23
35. Reinf Front Susp Lower Inr Bra	Mild Steel	2.00	0.50	0.23	1.00	0.45
Miscellaneous		1.5				
127. Reinf BDY CTR MNT For BDY I	Mild Steel	1.50	0.46	0.21	0.92	0.42
88. Member Front Floor Cross OTR	Mild Steel	1.25	0.46	0.21	0.92	0.42
55. Reinf Dash Panel @ Bracket Ma	Mild Steel	1.38	0.44	0.20	0.44	0.20
132. Bracket RR Bumper Ext	Mild Steel	1.75	0.40	0.18	0.80	0.36
143. Exhaust Hanger	Mild Steel	1.75	0.38	0.17	0.38	0.17
140. Reinf RR Susp Brkt	Mild Steel	1.50	0.38	0.17	0.76	0.34
63. Bracket Wiper Motor Mount LHD	Mild Steel	1.50	0.34	0.15	0.34	0.15
8. Spacer Battery Support	Mild Steel	1.50	0.31	0.14	0.31	0.14
205. Reinf Frt Door Upper Hinge	Mild Steel	1.25	0.30	0.14	0.60	0.27
210. Reinf Ctr Bdy Plr Upr Hinge	Mild Steel	1.25	0.30	0.14	0.60	0.27
223. Retainer DR Sec Seal RR	Mild Steel	0.70	0.30	0.14	0.60	0.27
94. Gusset Floor Panel Front	Mild Steel	1.00	0.29	0.13	0.58	0.26
90. PLT Parking Brake Support	Mild Steel	1.50	0.24	0.11	0.24	0.11
56. Bracket ACCL Pedal Stop LHD	Mild Steel	2.00	0.24	0.11	0.24	0.11
41. Bracket Jacking Lift Front	Mild Steel	1.38	0.23	0.10	0.46	0.21
220. Ext RR Corner Lower Pillar	Mild Steel	0.75	0.23	0.10	0.46	0.21
208. Reinf Center Plr Lwr Hinge	Mild Steel	1.25	0.22	0.10	0.44	0.20
93. Reinf Flr Pan RR	Mild Steel	1.00	0.22	0.10	0.22	0.10
204. Reinf Frt Door Lower Hinge	Mild Steel	1.25	0.20	0.09	0.40	0.18
68. Reinf Wiper Pivot Shaft Mountin	Mild Steel	1.25	0.18	0.08	0.18	0.08
229. Door Striker Plate	Mild Steel	3.00	0.17	0.08	0.68	0.31
28. Reinf Front Bumper Mounting	Mild Steel	1.50	0.15	0.07	0.30	0.14
40. Reinf Front Susp Lower OTR Br	Mild Steel	1.50	0.15	0.07	0.30	0.14
51. Reinf Floor SD Member INR RR	Mild Steel	1.50	0.15	0.07	0.30	0.14
64. Bracket Elec Cont Processor	Mild Steel	1.00	0.15	0.07	0.15	0.07
27. Bracket Master Cylinder Attachi	Mild Steel	2.00	0.15	0.07	0.15	0.07
209. Reinf RR Door Check	Mild Steel	1.25	0.13	0.06	0.26	0.12
130. Seat Belt Anchor (Inboard)	Mild Steel	2.00	0.13	0.06	0.26	0.12
133. RNF Floor Side Member at BDY	HSLA	3.00	0.13	0.06	0.52	0.24
137. Seat Belt Anchor (Outboard)	Mild Steel	2.00	0.13	0.06	0.52	0.24
128. Support Fuel Tank FRT INR	Mild Steel	2.00	0.13	0.06	0.26	0.12
13. Bracket Air Bag Sensor	Mild Steel	1.50	0.11	0.05	0.22	0.10
65. Bracket Instru Panel CTR	Mild Steel	1.50	0.11	0.05	0.11	0.05
67. Bracket Wiper SPDL Support LH	Mild Steel	1.25	0.11	0.05	0.11	0.05
126. Reinf Plt Master Ctrl Hole RR	Mild Steel	2.00	0.11	0.05	0.11	0.05
86. Bracket Front Seat MTG Front	Mild Steel	2.00	0.11	0.05	0.44	0.20
30. Bracket Module Mounting	Mild Steel	1.00	0.10	0.05	0.10	0.05
225. Filler Qtr Panel RR	Mild Steel	0.75	0.10	0.05	0.20	0.09
31. Bracket Elect Conctr Twr Mount	Mild Steel	2.00	0.10	0.05	0.10	0.05
125. Support Fuel Tank RR	Mild Steel	2.00	0.10	0.05	0.20	0.09
26. Bracket Power Str Res Susp	Mild Steel	2.00	0.09	0.04	0.09	0.04

AUTO BIW TCM: DEFINITION INPUTS - CONTOUR Closures
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Case: **Ford Contour**
Code: **Steel**

#	PANEL FABRICATION	Material	Calc Mass (kg)	Surface Area (cm^2)	Blank Area (cm^2)	Wall Thick (mm)	Piece Count
1	Hood Outer	Steel Ext. App.	8.30	14,095	16,068	0.75	1
2	Decklid Outer	Steel Ext. App.	6.61	11,220	12,678	0.75	1
3	Fender	Steel Ext. App.	2.18	3,700	5,439	0.75	2
4	Front Door Outer	Steel Ext. App.	9.58	16,267	23,262	0.75	2
5	Rear Door Outer	Steel Ext. App.	8.65	14,687	21,590	0.75	2
6	Hood Inner	Steel Mild Struc	5.70	12,100	16,335	0.60	1
7	Decklid Inner	Steel Mild Struc	4.24	9,000	11,610	0.60	1
8	Front Door Inner	Steel Mild Struc	4.52	9,600	14,976	0.60	2
9	Rear Door Inner	Steel Mild Struc	4.76	10,100	15,857	0.60	2
10	Inner/Outer Assy	none	0.00	0	0	0.00	6

Appendix II: Gas Costs

The **present value** of the fuel savings of an aluminum vehicle over a steel vehicle due to the higher mileage of an aluminum vehicle is a function of the gasoline price, the discount rate and the number of years over which the useful life (the number of miles the vehicle can be driven before being scrapped) is consumed.

The tables show the cost of the fuel consumed over the life of the vehicle for aluminum and steel vehicles as well as their difference (saving) for different gasoline pump prices. The actual cost is shown in the "Arithmetic" column while the present value of the actual cost discounted at 7% APR is shown in the "Discounted" column. The actual cost is higher the present value because it does not take the time value of money into account. The fuel savings are given in the "Differential" row both as present value and actual cost.

The tables look at two scenarios: 10 years at 12,000 miles per year and 5 years at 24,000 miles per year. The tables show that when the mileage is accumulated over a shorter period of time, present value of the fuel savings is more.

10 year - 12000 Miles per year

	Gasoline Price Per Gallon									
	$1		$2		$3		$4		$5	
	Arithmetic	Discounted	Arithmetic	Discounted	Arithmetic	Discounted	Arithmetic	Discounted	Arithmetic	Discounted
Steel	$5,529.95	$3,965.48	$11,059.91	$7,930.95	$16,589.86	$11,896.43	$22,119.82	$15,861.90	$27,649.77	$19,827.38
Aluminum	$4,780.88	$3,428.32	$9,561.75	$6,856.64	$14,342.63	$10,284.96	$19,123.51	$13,713.28	$23,904.38	$17,141.60
Differential	$749.08	$537.16	$1,498.15	$1,074.31	$2,247.23	$1,611.47	$2,996.31	$2,148.62	$3,745.39	$2,685.78

5 year - 24000 Miles per year

	Gasoline Price Per Gallon									
	$1		$2		$3		$4		$5	
	Arithmetic	Discounted	Arithmetic	Discounted	Arithmetic	Discounted	Arithmetic	Discounted	Arithmetic	Discounted
Steel	$5,529.95	$4,652.37	$11,059.91	$9,304.74	$16,589.86	$13,957.11	$22,119.82	$18,609.48	$27,649.77	$23,261.85
Aluminum	$4,780.88	$4,022.17	$9,561.75	$8,044.34	$14,342.63	$12,066.50	$19,123.51	$16,088.67	$23,904.38	$20,110.84
Differential	$749.08	$630.20	$1,498.15	$1,260.40	$2,247.23	$1,890.60	$2,996.31	$2,520.81	$3,745.39	$3,151.01

	10 Year Cycle		5 Year Cycle	
	Steel	Aluminum	Steel	Aluminum
Interest %	7	7	7	7.000
Mileage(MPG)	21.7	25.1	21.7	25.100
Annual Miles Driven	12000	12000	24000	24000.000
Years	10	10	5	5.000
Gasoline Price $/G	1	1	1	1.000

	10 Years				5 Years			
I	$5,529.95	$3,965.48	$4,780.88	$3,428.32	$5,529.95	$4,652.37	$4,780.88	$4,022.17
	Steel		Aluminum		Steel		Aluminum	
Month	Actual Price	Discounted Price	Actual Price	Discounted Price	Actual Price	Discounted Price	Actual Price	Discounted Price
1	46.0829493	45.814941	39.8406375	39.6089327	92.165899	91.6298812	79.681275	79.2178654
2	46.0829493	45.548491	39.8406375	39.3785755	92.165899	91.0969812	79.681275	78.7571511
3	46.0829493	45.28359	39.8406375	39.1495581	92.165899	90.5671804	79.681275	78.2991161
4	46.0829493	45.02023	39.8406375	38.9218725	92.165899	90.0404608	79.681275	77.843745
5	46.0829493	44.758402	39.8406375	38.6955111	92.165899	89.5168045	79.681275	77.3910222

6	46.0829493	44.498097	39.8406375	38.4704662	92.165899	88.9961937	79.681275	76.9409324
7	46.0829493	44.239305	39.8406375	38.2467301	92.165899	88.4786106	79.681275	76.4934602
8	46.0829493	43.982019	39.8406375	38.0242952	92.165899	87.9640377	79.681275	76.0485904
9	46.0829493	43.726229	39.8406375	37.8031539	92.165899	87.4524575	79.681275	75.6063079
10	46.0829493	43.471926	39.8406375	37.5832988	92.165899	86.9438525	79.681275	75.1665975
11	46.0829493	43.219103	39.8406375	37.3647222	92.165899	86.4382054	79.681275	74.7294445
12	46.0829493	42.96775	39.8406375	37.1474169	92.165899	85.935499	79.681275	74.2948338
13	46.0829493	42.717858	39.8406375	36.9313754	92.165899	85.4357163	79.681275	73.8627508
14	46.0829493	42.46942	39.8406375	36.7165903	92.165899	84.9388403	79.681275	73.4331806
15	46.0829493	42.222427	39.8406375	36.5030544	92.165899	84.4448539	79.681275	73.0061088
16	46.0829493	41.97687	39.8406375	36.2907603	92.165899	83.9537405	79.681275	72.5815207
17	46.0829493	41.732742	39.8406375	36.0797009	92.165899	83.4654833	79.681275	72.1594019
18	46.0829493	41.490033	39.8406375	35.869869	92.165899	82.9800656	79.681275	71.739738
19	46.0829493	41.248736	39.8406375	35.6612574	92.165899	82.4974711	79.681275	71.3225149
20	46.0829493	41.008842	39.8406375	35.4538591	92.165899	82.0176833	79.681275	70.9077182
21	46.0829493	40.770343	39.8406375	35.2476669	92.165899	81.5406857	79.681275	70.4953339
22	46.0829493	40.533231	39.8406375	35.042674	92.165899	81.0664623	79.681275	70.0853479
23	46.0829493	40.297498	39.8406375	34.8388732	92.165899	80.5949969	79.681275	69.6777463
24	46.0829493	40.063137	39.8406375	34.6362576	92.165899	80.1262734	79.681275	69.2725153
25	46.0829493	39.830138	39.8406375	34.4348205	92.165899	79.660276	79.681275	68.869641
26	46.0829493	39.598494	39.8406375	34.2345548	92.165899	79.1969886	79.681275	68.4691097
27	46.0829493	39.368198	39.8406375	34.0354539	92.165899	78.7363957	79.681275	68.0709078
28	46.0829493	39.139241	39.8406375	33.8375109	92.165899	78.2784814	79.681275	67.6750218
29	46.0829493	38.911615	39.8406375	33.6407191	92.165899	77.8232303	79.681275	67.2814382
30	46.0829493	38.685313	39.8406375	33.4450718	92.165899	77.3706269	79.681275	66.8901435
31	46.0829493	38.460328	39.8406375	33.2505623	92.165899	76.9206556	79.681275	66.5011246
32	46.0829493	38.236651	39.8406375	33.0571841	92.165899	76.4733014	79.681275	66.1143681
33	46.0829493	38.014274	39.8406375	32.8649305	92.165899	76.0285488	79.681275	65.7298609
34	46.0829493	37.793191	39.8406375	32.673795	92.165899	75.5863828	79.681275	65.3475899

35	46.0829493	37.573394	39.8406375	32.4837711	92.165899	75.1467884	79.681275	64.9675422
36	46.0829493	37.354875	39.8406375	32.2948523	92.165899	74.7097505	79.681275	64.5897047
37	46.0829493	37.137627	39.8406375	32.1070323	92.165899	74.2752544	79.681275	64.2140646
38	46.0829493	36.921643	39.8406375	31.9203046	92.165899	73.8432852	79.681275	63.8406091
39	46.0829493	36.706914	39.8406375	31.7346628	92.165899	73.4138283	79.681275	63.4693257
40	46.0829493	36.493434	39.8406375	31.5501007	92.165899	72.986869	79.681275	63.1002015
41	46.0829493	36.281196	39.8406375	31.366612	92.165899	72.5623928	79.681275	62.733224
42	46.0829493	36.070193	39.8406375	31.1841904	92.165899	72.1403852	79.681275	62.3683808
43	46.0829493	35.860416	39.8406375	31.0028298	92.165899	71.720832	79.681275	62.0056595
44	46.0829493	35.651859	39.8406375	30.8225239	92.165899	71.3037188	79.681275	61.6450477
45	46.0829493	35.444516	39.8406375	30.6432666	92.165899	70.8890314	79.681275	61.2865331
46	46.0829493	35.238378	39.8406375	30.4650518	92.165899	70.4767558	79.681275	60.9301036
47	46.0829493	35.033439	39.8406375	30.2878735	92.165899	70.0668779	79.681275	60.575747
48	46.0829493	34.829692	39.8406375	30.1117256	92.165899	69.6593837	79.681275	60.2234512
49	46.0829493	34.62713	39.8406375	29.9366022	92.165899	69.2542594	79.681275	59.8732044
50	46.0829493	34.425746	39.8406375	29.7624972	92.165899	68.8514913	79.681275	59.5249945
51	46.0829493	34.225533	39.8406375	29.5894048	92.165899	68.4510656	79.681275	59.1788097
52	46.0829493	34.026484	39.8406375	29.4173191	92.165899	68.0529686	79.681275	58.8346382
53	46.0829493	33.828593	39.8406375	29.2462342	92.165899	67.657187	79.681275	58.4924684
54	46.0829493	33.631854	39.8406375	29.0761443	92.165899	67.2637071	79.681275	58.1522886
55	46.0829493	33.436258	39.8406375	28.9070436	92.165899	66.8725155	79.681275	57.8140871
56	46.0829493	33.2418	39.8406375	28.7389263	92.165899	66.4835991	79.681275	57.4778526
57	46.0829493	33.048472	39.8406375	28.5717868	92.165899	66.0969446	79.681275	57.1435736
58	46.0829493	32.856269	39.8406375	28.4056193	92.165899	65.7125387	79.681275	56.8112386
59	46.0829493	32.665184	39.8406375	28.2404182	92.165899	65.3303684	79.681275	56.4808365
60	46.0829493	32.47521	39.8406375	28.0761779	92.165899	64.9504208	79.681275	56.1523559
61	46.0829493	32.286341	39.8406375	27.9128928				
62	46.0829493	32.098571	39.8406375	27.7505573				
63	46.0829493	31.911892	39.8406375	27.5891659				

64	46.0829493	31.7263	39.8406375	27.4287132
65	46.0829493	31.541786	39.8406375	27.2691936
66	46.0829493	31.358346	39.8406375	27.1106017
67	46.0829493	31.175972	39.8406375	26.9529322
68	46.0829493	30.994659	39.8406375	26.7961796
69	46.0829493	30.814401	39.8406375	26.6403387
70	46.0829493	30.635191	39.8406375	26.4854041
71	46.0829493	30.457023	39.8406375	26.3313706
72	46.0829493	30.279892	39.8406375	26.1782329
73	46.0829493	30.10379	39.8406375	26.0259858
74	46.0829493	29.928713	39.8406375	25.8746242
75	46.0829493	29.754654	39.8406375	25.7241429
76	46.0829493	29.581607	39.8406375	25.5745367
77	46.0829493	29.409567	39.8406375	25.4258006
78	46.0829493	29.238527	39.8406375	25.2779295
79	46.0829493	29.068482	39.8406375	25.1309184
80	46.0829493	28.899426	39.8406375	24.9847623
81	46.0829493	28.731353	39.8406375	24.8394562
82	46.0829493	28.564257	39.8406375	24.6949952
83	46.0829493	28.398133	39.8406375	24.5513743
84	46.0829493	28.232976	39.8406375	24.4085887
85	46.0829493	28.068779	39.8406375	24.2666335
86	46.0829493	27.905537	39.8406375	24.1255039
87	46.0829493	27.743244	39.8406375	23.985195
88	46.0829493	27.581895	39.8406375	23.8457022
89	46.0829493	27.421485	39.8406375	23.7070206
90	46.0829493	27.262007	39.8406375	23.5691456
91	46.0829493	27.103457	39.8406375	23.4320725
92	46.0829493	26.945829	39.8406375	23.2957965

93	46.0829493	26.789118	39.8406375	23.160313
94	46.0829493	26.633318	39.8406375	23.0256176
95	46.0829493	26.478424	39.8406375	22.8917054
96	46.0829493	26.324431	39.8406375	22.7585721
97	46.0829493	26.171334	39.8406375	22.6262131
98	46.0829493	26.019127	39.8406375	22.4946238
99	46.0829493	25.867805	39.8406375	22.3637998
100	46.0829493	25.717364	39.8406375	22.2337367
101	46.0829493	25.567797	39.8406375	22.10443
102	46.0829493	25.4191	39.8406375	21.9758753
103	46.0829493	25.271268	39.8406375	21.8480682
104	46.0829493	25.124295	39.8406375	21.7210045
105	46.0829493	24.978178	39.8406375	21.5946797
106	46.0829493	24.83291	39.8406375	21.4690896
107	46.0829493	24.688487	39.8406375	21.3442299
108	46.0829493	24.544904	39.8406375	21.2200964
109	46.0829493	24.402156	39.8406375	21.0966848
110	46.0829493	24.260238	39.8406375	20.9739909
111	46.0829493	24.119146	39.8406375	20.8520106
112	46.0829493	23.978874	39.8406375	20.7307397
113	46.0829493	23.839418	39.8406375	20.6101741
114	46.0829493	23.700773	39.8406375	20.4903097
115	46.0829493	23.562934	39.8406375	20.3711424
116	46.0829493	23.425897	39.8406375	20.2526681
117	46.0829493	23.289657	39.8406375	20.1348829
118	46.0829493	23.154209	39.8406375	20.0177827
119	46.0829493	23.019549	39.8406375	19.9013635
120	46.0829493	22.885673	39.8406375	19.7856214