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Barriers to Adopting Structural Composites at the Traditional U.S. Automotive Manufacturers

by

Michael S. Flynn
Bruce M. Belzowski

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University of Michigan Transportation Research Institute
Ann Arbor Michigan

Preface

In February of 1994, the Automotive Composites Consortium (ACC) and Owens-Corning Fiberglas Corporation jointly contracted with the University of Michigan's Office for the Study of Automotive Transportation (OSAT) to examine the barriers, processes, and issues that have slowed the adoption of structural composites in the automotive industry. OSAT had just completed a project on the recycling of automotive plastics and a project on the barriers the Big Three encounter in learning technology from their Japanese partners. Barriers to composites adoption provided a welcome opportunity to pursue these kinds of learning and change issues further.

OSAT's efforts were designed to provide information bearing on two critical aspects of composites adoption: the current barriers, and what developments might alleviate them. This report describes our research efforts, results, and recommendations to the ACC. We believe it provides useful information on the barriers to the wider adoption of structural composites and identifies the broad parameters of strategic efforts that would promote their wider appropriate use in automotive applications.

OSAT thanks the ACC representatives who provided us with support, guidance, and education on the multifaceted world of automotive composites, and those executives and specialists at the Big Three who graciously offered the time and patience required for our interviews. The authors also wish to thank two colleagues from the Transportation Research Institute, Brett Smith of OSAT and Albert Horsmon of the Marine Systems Division, whose interviewing efforts contributed substantially to this project. If shortcoming remain after the exceptional efforts of our clients, colleagues, and interviewees, we accept sole responsibility for them.

Executive Summary

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Background. The use of automotive plastics has increased over the past decade, but the rate has been slower than their many advantages might suggest. These advantages include design flexibility, part integration, corrosion resistance, fuel conservation (through weight reduction), and cost for low volume programs. Structural composites are fiber reinforced polymeric materials for a wide range of demanding and high stress applications. While structural composites typically avoid some of the problems (such as color matching) that often confront applications more visible to consumers, their growth may be even slower than other plastic materials.

What has slowed the use and application of automotive structural composites? We investigated the barriers that might retard their adoption and diffusion. The heart of our study was a series of interviews with 27 executives and engineers at the Big Three, ranging in rank from vice president to materials engineer. We hope the information we developed will provide an important stimulus to overcoming the barriers to structural composites, whether rooted in appropriate or inappropriate considerations.

Material Decisions. Selecting a certain material for a particular application in a specific vehicle is a highly complex decision process. After all, it involves numerous participants and goals as well as constraints imposed by the marketplace, competitors' decisions, and regulatory and legal initiatives. While mistakes in material selection decisions rarely reach the customer, they do occur. Our respondents attribute such errors to inadequate knowledge, procedural errors, and reliance on suppliers' claims.

Our respondents identified many participants in the material selection process, including suppliers, who typically originate suggestions for material changes like the substitution of structural composites for metals. This suggests a healthy and relatively open materials system, although one that may require multiple strategies to secure acceptance for a particular material. Rejections of a new material are more concentrated and occur later in the decision process, with a sizable majority happening within the vehicle organization itself, rather than in the supporting engineering and technical units.

Corporate Learning. The vehicle manufacturers spread their information nets fairly wide to learn about new materials. They devote roughly equal attention to learning sources internal to the companies, their supply base, and other external sources, such as associations. The suppliers play a role here that is consistent with their notable role in suggesting new materials. To be sure, when making material selection decisions, automakers primarily rely on internal sources, although suppliers play a role here as well.

Nevertheless, respondents believe that much of the corporate conventional wisdom about composites is based on erroneous information, and that good levels of understanding about composites is most often restricted to material specialists. That may be an important barrier, because composites will probably not achieve wider adoption until designers and component engineers become comfortable with them, understanding them sufficiently to use them appropriately and to include them in designs.

Strategic Goals. While the Big Three lack specific policies regarding the substitution of structural composites for metals, such decisions clearly are shaped by other policies, such as weight reduction, and standard practices, such as cost containment. Some strategic goals at the Big Three support increased use of structural composites, while others mitigate against their wider application. The CAFE goal of fuel economy drives weight reduction and these, together with cost reduction and specific product and/or process goals, form the most important strategic goals driving structural composites adoption. On the other hand, attention to cost reductions and timing discipline tend to inhibit their adoption. Today's intensely competitive environment restricts experiments with untried materials, as program directors are reluctant to build further uncertainty into an already complex and uncertain schedule.

The Value of Structural Composites. We explored the value, or the net advantages and disadvantages of structural composites with our respondents. First, over half our respondents directly identified weight reduction and lower investment cost for low volume programs as major advantages, and the industry's own uneasiness and the overall cost of composites as major disadvantages. These reports of industry uneasiness are intriguing. Our question focused on the material itself, yet the industry's reaction to composites is their most frequently mentioned disadvantage. Thus, barriers to the adoption of composites include attributes of both the material and the decision makers.

Second, respondents identified more applications for structural composites as suitable than as unsuitable. They view body structures and components as particularly suitable, while engine and drive train parts and components present a more mixed picture, including similar frequencies of suitable and unsuitable applications. Interestingly, respondents were more likely to mention generic types of applications, rather than specific parts, when identifying unsuitable applications than when identifying suitable ones. Perhaps this reflects their uneasiness and uncertainty. Finally, respondents also compared composites with metals across the life cycle of the vehicle, reporting similar concerns for the vehicle use stage, but substantially more problems for composites at both the production and retirement stages.

Barriers and Facilitators. We asked respondents to review a list of 46 potential barriers and select the most serious concerns, ones that generally play an important role in decisions against adopting structural composites. More than half of the interviews identified recycling, total cost, crash energy absorption, concerns about design methods and capabilities, manufacturing variability, and adhesive bonding. Half identified another 4: difficulty identifying/measuring the benefits of adoption, difficulty integrating new materials into an existing framework, concerns about supplier capability, and assembly requirements. Thus 10 barriers are fairly widespread, covering a mixture of material attributes and industry comfort with the material.

More than half of our respondents selected 6 of the 18 facilitators we presented them. These 6 factors that might accelerate composite adoption are clear evidence of the cost/benefit of adoption; vehicle objectives respectively for weight reduction, fuel economy, and cost reduction; design attributes; and low costs for low volume production. Respondents mentioned facilitators less than half as often as they mentioned barriers, and tended to discuss them as hypothetical. That is, they mentioned developments and described circumstances that might, if they came to pass, expand the automotive application of structural composites. Barriers are currently both more frequent and more real to our respondents than are facilitators.

A number of general themes emerged in these interviews. First, the competitive environment does not support experimentation with new materials of any type unless there is a clearly defined benefit. Second, composites are definitely tracking behind the metals—especially aluminum—as lighter weight alternatives to steel. Third, there are widespread serious concerns about the costs of composites.

Strategies for Accelerating Adoption. No one barrier, whether real or imagined, prevents the adoption of structural composites, so there is no one simple and straightforward "quick fix" strategy or tactic to assure their rapid deployment. Effective strategies will combine different elements that target different problems into a coherent and complementary program. Moreover, the composites industry dares not assume that the only barrier has been a stodgy, change-resistant automotive industry. It must recognize that it has oversold and underdelivered in the past.

These interviews suggest that demonstration projects are likely to be the single most effective step for accelerating the application of automotive structural composites. However, process improvements, information efforts to reduce uncertainties, enhanced recycling capability, improved crash modeling, and product improvements receive some endorsement as well.

A fundamental issue facing the composites industry is whether or not a strategy of gradualism can be effective. The manufacturers are more likely to adopt structural composites in a limited application, where cost and quality can be better controlled and the industry can develop its technical and human capabilities. However, that means that composites will continue to be the odd material in a metals system, requiring compromises in manufacturing and product design, perhaps ensuring disappointing experiences and thus building more resistance.

We suspect that there are now and will be in the future components and parts that are simultaneously major enough to attract the attention of the automotive community, sufficiently insulated in production to show composites at their best, advantageously executed in composites, and affordable in today's climate. Successful projects built around these opportunities must be documented in detail to persuade a skeptical industry.

Perhaps no one company will undertake the costs inherent in a full exploration of structural composites, suggesting that a consortium made up of automakers, resin producers, and molders might be a useful way to provide the capital and human resources necessary for such an effort. One advantage of this is that it puts the automaker in direct contact with the material suppliers, who may be better positioned to work with them. Consortia efforts might include modeling and testing in the safety arena, developing industry standards through SAE, funding vehicle manufacturer and component supplier training and education through AIAG, ASI, SAE, etc. Evaluating life cycle environmental impacts and seeking more recyclable composites may also be appropriate consortia activities.

The composites industry must recognize the reality of past problems in implementing structural composites in automotive production, and avoid patronizing and even insulting potential customers. The automotive manufacturers must recognize that their conceptual habits and operational investments are sources of resistance to composites applications, perhaps inappropriately so. The composites industry needs to recognize these barriers and circumstances as pragmatic concerns and overcome them as any other barrier.

Table of Contents

ABSTRACT

Structural composites seem to have low automotive application rates in view of their numerous advantages, especially since they do not share some of the recognized risks of plastics, such as unacceptable color-matching. This report presents the results of an investigation into the barriers and obstacles to their wider adoption at the Big Three automakers, based on interviews with 27 executives and engineers, ranging in rank from vice president to materials engineer.

Applications of structural composites face many and varied barriers. Half or more of our interviewees identified 10 barriers (from a list of 46) as generally playing an important role in decisions against adopting structural composites. These barriers cover a wide range, spanning material attributes, concerns about supplier capabilities, and the automakers' own general lack of experience and comfort with the material.

Still other barriers are rooted in the intensely competitive environment, where apprehension has fostered a more cautious strategy geared to mistake avoidance rather than to innovation for competitive differentiation, and in the difficulties of effectively integrating composites into a production environment suited to metals. Evidence from our interviews reinforces the importance of apprehensions and concerns about recycling and disposal. Recycling is the single most frequently selected barrier to composite adoption, and interviewees report that composites trail the metals in life cycle advantages and disadvantages, especially at the recycling stage.

The automakers interest in structural composites continues, but no one simple and straightforward "quick fix" strategy can assure their wider deployment. Demonstration projects can help, and the composites industry can alleviate its own short-comings while helping the automotive industry gain experience and comfort with the material. Nevertheless, the composites industry faces a serious and perplexing challenge: how to persuade industry decision-makers that the materials' advantages are substantial and sustainable in a competitive environment that limits the very innovation and testing that could provide the necessary evidence.

Barriers to Adopting Structural Composites at the Traditional U.S. Automotive Manufacturers

Introduction

The automotive industry is a major consumer of materials. In 1991 the industry produced just under 9 million vehicles, reaching its lowest output since 1982.[1] Yet it still accounted for a substantial share of the total U.S. consumption of numerous materials that year, including over 70 percent of lead and natural rubber, over 30 percent of synthetic rubber, platinum, and iron, and 10 percent or more of zinc, aluminum, steel, and copper. The industry also accounted for a small but important share of plastics consumption, at about 3 percent of the total.[2]

Automotive use of plastics has shown substantial and steady growth over the past decade and a half, as measured by total plastics weight in the vehicle.[3] This growth is to some extent driven by the regulatory pressure to improve vehicle fuel efficiency embodied in Corporate Average Fuel Economy (CAFE) standards.[4] Lighter-weight materials are an important element of the strategy to achieve enhanced fuel efficiency without sacrificing consumer preferences for size and performance. Nevertheless, plastics growth has been more restrained than many observers expected in view of this specific fuel conservation benefit and the many attractive attributes they offer across a variety of automotive applications.[5]

Decision-making processes in the automotive industry can be extremely complex, reflecting the industry's sheer size, its number of participating companies, and its range of product offering. Moreover, decisions that result in the selection of a specific material

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[1]*AAMA Motor Vehicle Facts & Figures 1993*, (Washington, D.C.: American Automobile Manufacturers Association, 1993), p. 3.
[2]*AAMA Motor Vehicle Facts & Figures 1993, op. cit.*, p. 49.
[3]*AAMA Motor Vehicle Facts & Figures 1993, op. cit.*, p. 50.
[4]See, for example, data reported in Brett C. Smith and Michael V. DiBernardo, *Delphi VII Forecast and Analysis of the North American Automotive Industry, vol. 3: Materials*, (Ann Arbor, MI: Office for the Study of Automotive Transportation, 1994), pp. 27-29.
[5]See, for example, Michael S. Flynn, David J. Andrea, David E. Cole, Richard L. Doyle, and Sean P. McAlinden, "Recycling Automotive Plastics," in *XXIV FISITA Congress Technical Papers. The Vehicle and the Environment: Volume 2* (London: Mechanical Engineering Publications, 1992), pp. 135-142.

for a particular application in a certain vehicle are among the most complex of all. Such material decisions are complex in terms of the number and variety of participants, the array of possible materials, and the range of potential consequences of a particular decision. Thus designers, product and manufacturing engineers, purchasing agents, and suppliers all try to satisfy their often conflicting goals and considerations in the material selection arena. They must balance the differing attributes of candidate materials, such as weight, stiffness, flexibility, and cost, against the requirements of widely different specific applications. And the decision must respond to the myriad constraints and demands imposed by the marketplace, competitors' decisions, and regulatory and legal initiatives.[6]

Nevertheless, it does seem to some observers that the rate of diffusion of a particular type of automotive plastic material, structural composites, has been especially slow in view of the materials' inherent properties and the requirements for such applications. Structural composites have been used by each of the Big Three, so they have experience with these materials. For example, Chrysler has used structural composites in a fuel tank support strut in the Minivan, Ford in the Ranger leaf spring, and GM in the Eldorado bumper beam. However, that experience is typically more of an experimental or testing nature, rather than full scale implementation in a high volume program. Therefore it is an open question how widely the information and knowledge from those applications is diffused.

This report details the results of a systematic exploration of the factors and concerns of automotive decision-makers that have influenced the industry's adoption of structural composites. The authors' hope is that the information contained herein will accomplish two goals. First, we hope it will assist the automotive industry in making material selection decisions in an increasingly complex and often contradictory environment. Second, we hope the information will help proponents of wider applications of composites understand the barriers such materials face. Such information can provide an important, although not sufficient, stimulus to overcoming those barriers.

Background

The Automotive Composites Consortium (ACC) and Owens-Corning Fiberglas Corporation contracted with the University of Michigan's Office for the Study of Automotive Transportation (OSAT) to undertake an examination of the barriers, processes, and issues that have slowed the adoption of structural composites in the automotive industry. This report provides information from that effort on the barriers to the wider adoption of structural composites and identifies the broad parameters of some strategic efforts that might promote their wider appropriate use in automotive applications.

Definition of Structural Composites. For project purposes, composites are defined as fiber reinforced polymeric materials. Structural and semi-structural applications cover a wide variety of demanding and high stress applications. These include body components like body sides, front end structures, cross-members, floor pans, and pickup boxes; suspension components such as linkages and leaf springs; bumper components such as beams and supports; interior components, like seat back/frame parts and instrument panel

[6]As many as 30 factors have been identified as criteria for varying material selection decisions. See David J. Andrea and Wesley R. Brown, *The Material Selection Process in the Automotive Industry,*_UMTRI Report # 93-40-5 , (Ann Arbor, MI: University of Michigan Transportation Research Institute, January 1994). In a recent study, material specialists rated a dozen factors as at least somewhat important in automotive material decisions. See Brett C. Smith and Michael V. DiBernardo, *op.cit.,* p. 15.

supports; drive shafts; wheels; and engine applications such as intake manifolds, rocker arm covers, and water pumps. However, body panels, a relatively frequent composite application, are excluded from consideration in this study unless they are integrated into the body structure.

Domains of Inquiry. The first challenge the project faced was to identify the potential barriers to wider implementation of structural composites. While the benefits of structural composites are probably well understood, the current rate of adoption and use suggests that there are blockers, factors, or selection criteria that are restricting their use in automotive applications. Are these barriers rooted in general resistance to change, or are there specific disadvantages and risks (whether perceived or real) associated with composites applications that outweigh their promised benefits? Moreover, are there specific barriers—such as cost, recyclability, life expectancy, actual experience data, etc.—that represent absolute hurdles or "killer criteria" that composites must satisfy before they receive serious consideration by automotive decision-makers? What is the relative importance or ranking of other barriers? Which ones are more or less critical? Are there competitor materials that appear to offer decision-makers a better risk-reward balance than structural composites?

The second major challenge was to recommend strategies for addressing the barriers we found. What type of information might overcome resistance based on different perceived risks? Will appropriate information on composite performance, or recasting the balance of costs and benefits address the shared concerns of the automakers? Are there ways to alter the decision-makers' perceptions of the comparative risk-reward situation of composites and their alternatives? How can key perceptual barriers be overcome, and will overcoming them expand the application of structural composites?

Method. Capturing the views, beliefs, and premises of all the actors that influence material selection decisions poses a dilemma. One method for gathering such data, the survey, is well suited to collecting masses of standard information from large groups, while another method, focused interviews, is better suited to collecting information more targeted and tailored to the individual respondent's experience and views. For a number of reasons, we decided to pursue these issues through a limited set of focused interviews.

First, appropriately designed and executed interviews elicit the direct information that identifies and amplifies the barriers, while they also provide a richness of detail that permits the identification of key problems and the development of strategies to address them. A properly executed survey typically provides more confidence about the extent and generality of specific barriers and concerns, but usually offers less information that helps to understand the basis of those barriers and to formulate response strategies.

Second, a major advantage of the survey is that the large numbers it can provide, based upon proper sampling procedures, yield a known probability of error. However, the material selection process is complex and the roles of participants vary considerably over product applications, vehicle programs, and companies. That essentially means that we lack the information to sample the decision-making *process* through its participants or to weight their responses analytically in a meaningful way, undermining the survey's major advantage over the interview.

Interviews. We sought appropriately targeted interviews at the three manufacturers, drawing on each company's representative to the ACC to nominate potential interviewees. The grounds for inclusion were broad, including the individual's knowledge, experience, organizational role, and general reputation as an important participant in material selection decisions. Our interviewees span the organizational ranks from a vice president of divisional engineering to functional material specialists in polymeric-based composites. While they do not form a representative sample in any sense, they provided us with a wide range of views and experiences, and useful and valuable information on the barriers to structural composites and possible methods of overcoming them.

As is often the case in these types of interview projects, we were not able to interview every respondent we targeted. In some cases, we were unable to schedule a mutually feasible time, in others, the individual recommended more suitable interviewees, and in a few, the interview candidate simply preferred not to participate.

We worked closely with our sponsors to develop and finalize the interview instrument, attached as appendix I, making particular efforts to focus the interview on the issues of structural composites, rather than on composites for other applications, or on automotive composites in general. However, our respondents' comments must be interpreted with caution, since it does appear that they sometimes spoke broadly to the issues surrounding more general uses of automotive plastics. In some instances this seemed to reflect respondent misunderstanding of how we used the term "structural composites"; in others, respondents simply preferred to comment more generally; and in still others, respondents appeared uncertain as to the distinctions we made among various plastics and uses.

We cannot clearly and unambiguously separate all the responses to focus on just those that solely target the material of interest, structural composites. Thus a comment that structural composites create problems for color matching may mean that the respondent is thinking of a structural application that can be seen (integrated body panels), or the more general class of composite applications (body panels), or even thermoplastic veneers (vinyl interior parts). Unfortunately, too much probing risks turning the interview conversation into a testing and challenging contest, and that typically restricts information. Therefore, readers of this report must be cautious in how they use the information from our respondents. In those instances where the mind set of the respondent may be particularly critical, further information should be gathered.

In a few instances, interviewees asked that colleagues join them for the interview or for particular parts of it. We have generally treated these interviews as one response, counting the distinct material contributed by the several participants, but not counting the common material more than once. That is, we treat the interviews, rather than the respondents, as our unit of analysis.

The distribution of interviews and respondents is displayed in table 1.

Table 1. Distribution of Interviews and Respondents, by Company

	Interviews	Respondents
Chrysler	8	10
Ford	6	6
GM	8	11
Total	22	27

We did not consciously seek different numbers of interviewees and interviews across the companies; rather it springs from and reflects two circumstances. First, the organization and scale of GM activities is simply more complex than either Ford's or Chrysler's, so one has to speak to more people to ensure similar scope and coverage in the research effort. Secondly, while Chrysler may be smaller scale than Ford, it has been particularly active in developing new vehicles over the past few years, and thus has made a large number of recent decisions to adopt or not to adopt automotive composites.

A final aspect of our interviews is important. We provided our respondents the normal guarantee of confidentiality, but we also asked them for their own views and experiences, and stressed that we did not consider them to be speaking for their companies. We felt it was important to personalize the interviews for two reasons. First, the feeling that one may be viewed as speaking for the company often imposes a level of caution and restraint that effectively embargoes important material. Second, we wished to capture the respondents' own views, perceptions, and experiences, a frame of reference that might easily be subordinated to an organizational perspective if they felt we viewed them as representing their companies or units.

Presentation of Results. Results from this kind of study risk two types misrepresentation of the overall results. First, the input from a few talkative respondents may dominate the analysis. This can happen when some respondents describe many more instances of particular response categories than do others, and the analysts simply count how often each category is mentioned, ignoring how many people made such mentions. Second, the reverse problem may occur, where differences in response amplitude across respondents is ignored. This might occur when we simply count the number of interviews that mention a category, but ignore the actual number of mentions for each category.

We present both numbers because they tell us different information about the group's views and opinions. We first present the total number of *mentions* of a particular response category, and the percentage each category comprises of all answers to the question. These numbers represent the total information and opinions of the group of respondents as a whole. We also present the number of *interviews* in which a category was mentioned at least once and the percentage that those interviews comprise of the total set of interviews, with a maximum of 22. These two numbers represent how the information and opinions are distributed across the group of respondents. This eliminates any distortions that might be caused by multiple mentions of a category by just a few respondents. Which of these two is more relevant depends on the question and how the information is to be used. An example of how to interpret these tables is shown on page 8-9, table 4.

Our interviews are not a sample in the statistical sense of that term. Additionally, they total a small number of cases. For these reasons, we present no statistical analysis, nor do we claim that these results are in any sense typical. Rather, we view them as exploratory and suggestive.

Differences Across Companies. This report contains no references to differences across companies. This is not the result of our analysis ignoring or suppressing such differences. Rather, evidence of such differences is extremely tenuous and scattered throughout our results, and the overwhelming pattern in these data is one of greater differences within companies than between companies. Where differences exist, they appear to be related to differences in the organization and scale of the companies, and essentially inconsequential in regards to the decisions to adopt or reject structural composites.

We now turn to the actual results of our interviews and analyses, beginning with an overview of the material selection process, to convey the complex and often convoluted process that new materials must successfully navigate before adoption.

The Material Selection Decision Process

Material Selection Decisions. The material selection process in the automotive industry is complex, subject to numerous constraints, and encompassing many decision points. The adoption of any new material (or the use of an old material in a new application) is a particularly daunting challenge, because the material must be evaluated from so many perspectives and by so many people with differing experiences, specialties, and responsibilities. We began our interview on the adoption of structural composites by first asking our respondents to comment on a simplified flow chart of the automotive material selection process, displayed in figure 1.[7] We asked them whether this is a reasonable description of the process at their company, and where the suggestion for a material change, such as the substitution of structural composites for metals, typically originates. We also ascertained where the decision to reject a proposed adoption would typically occur.

Five of our respondents felt this flow chart provides a reasonable overview and description of the automotive material selection process. Eight viewed it as close, and reasonable with some minor modifications, such as two way arrows of influence and decision, portraying much of the activity as simultaneous rather than sequential, and elaborating the decisional activities proximate to their own location. Nine did not find it a reasonable approximation, often noting the absence of advanced functions and the like.

Differences in the comments of respondents who called for minor modifications to the flow chart and those who rejected it were often small, sometimes seeming to reflect more their initial tendencies to say yes or no rather than any real difference in their views. For our purposes, such differences are not important. What is important is that the flow chart reasonably approximates the material selection process at a broad conceptual level, or if it does not, it is because it is not sufficiently detailed and complex. Material decisions are indeed complex, complicating our analysis, and any strategies for encouraging the adoption of new materials. Perhaps the most noteworthy result is a general one: Even here we found little evidence of real differences across the three companies, as evidenced in table 2.

Table 2. Flow Chart Evaluations, by Company

	Company			
Evaluations	*Chrysler*	*Ford*	*GM*	*Total*
Reasonable as is	2	2	1	5
Minor modifications	3	2	3	8
Substantially different	3	2	4	9

[7] David J. Andrea and Wesley R. Brown, *The Material Selection Process in the Automotive Industry, op. cit.*

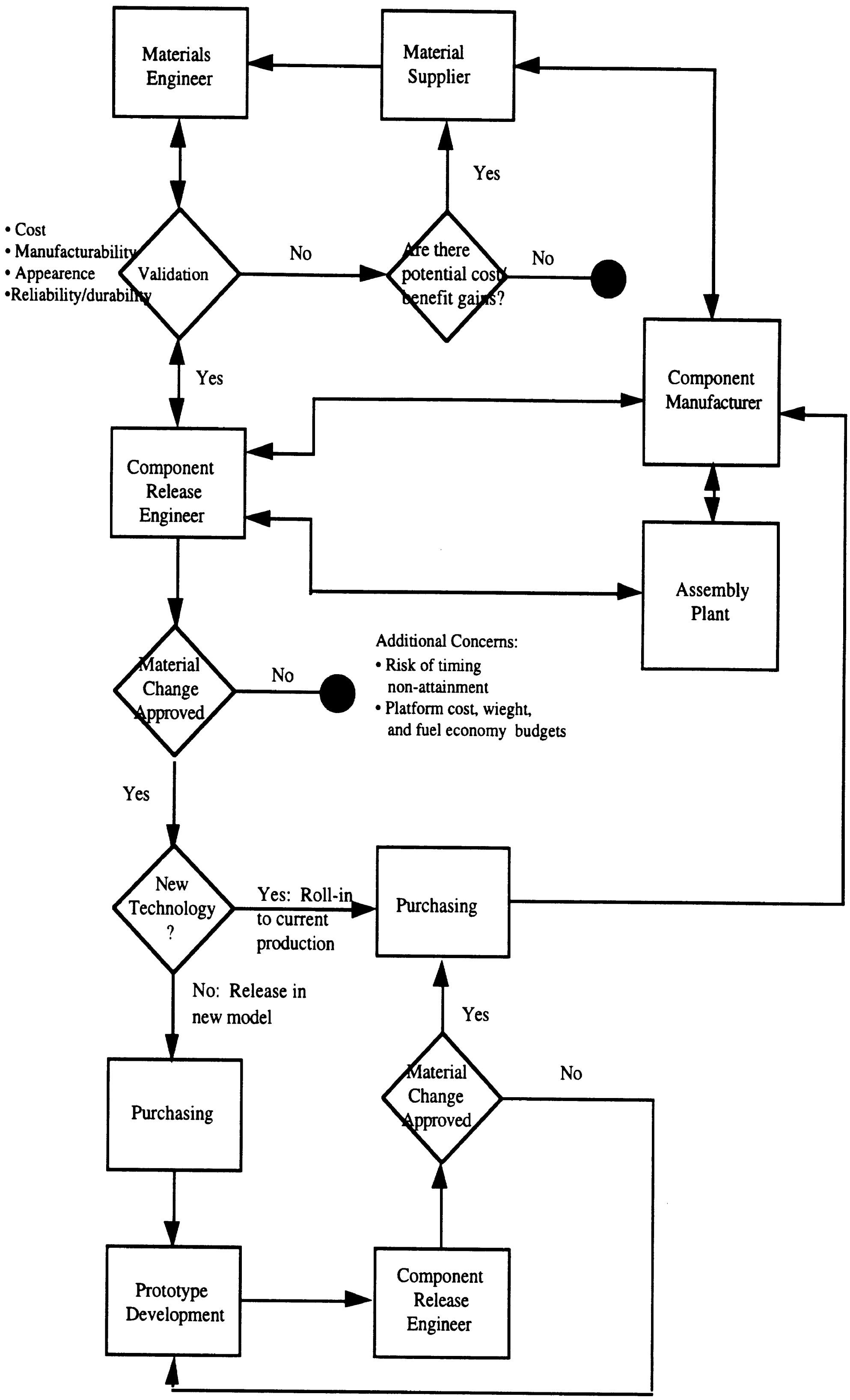

FIGURE 1 Automotive Material Selection Process

It is clear that a suggested material change can originate from numerous sources, and that there really is not one typical source that covers the majority of cases. Thus our respondents identified component engineers (9 times), suppliers (8), material engineers and advanced functions (5 each), vehicle teams (2), and purchasing (1) as sources for suggested materials changes. This is probably evidence of a healthy and relatively open materials suggestion system, although it may make it more difficult to craft a strategy to gain acceptance for a particular material. Multiple possible entry points probably increase the challenge of gaining acceptance for a new material or application whether the originators are suppliers with particular brands to sell, or material engineers within the company who believe they have found an important resource.

The respondents feel that decisions to reject a new material are much more concentrated, with the majority (16) of reported rejection decisions occurring in the vehicle or platform organization or team, and another 5 reporting rejections most likely to come from the component engineer. Of course, the component release engineer may also be a member of the platform team, an increasingly frequent arrangement.

The points of the process where both suggestions and rejections of new materials typically occur can be examined from the perspective of how early or late in the process they occur. The results of such an analysis are displayed in table 3.

Table 3. Identified Material Decisions, by Process Stage

	Stage					
Decision	*Supplier*	*Advanced Functions*	*Material Engineer*	*Component Engineer*	*Team/ Program*	*Manu-facturing*
Originate	8	5	5	9	2	0
Reject	0	1	1	5	16	2

These data strongly suggest two important, related aspects of how new materials come to be considered for adoption and how they are likely to be rejected. First, considerations for adoption come from numerous stages of the process, while rejections tend to be concentrated in the vehicle organization. Second, rejections appear to be concentrated in the later stages of the process, while suggestions span the full range.

These results and interpretations must be treated with caution. Many of our respondents are members of vehicle organizations, and may not be in a position to know about materials that were rejected at earlier stages. They see a wide variety of candidates coming from numerous sources, but only if they have survived until fairly late in the process. If a material is rejected earlier in the process they may not be aware it was considered, or they might lack detailed information on where it was rejected. However, to the extent that these results are accurate, this late rejection imposes a cost burden on suppliers. They may find themselves investing time, funds, and effort in promoting the adoption of a particular composite throughout the product development cycle, only to find it rejected fairly late in that process.

We asked our respondents to describe the typical mistakes companies make in these complex material selection decisions, and these results are presented in table 4. As we stated in the Background section above, we devised a table format that should help eliminate any bias caused by one or two respondents mentioning the same category many times. The first two columns *(Mentions)* of table 4 display the number of times a mistake is mentioned and the percentage each type of mistake represents of all the mistakes mentioned. For example, inadequate knowledge was mentioned as a mistake 12 times, constituting 36 percent of all mentions. The third and fourth columns *(Interviews)* display the number of interviews where each mistake was mentioned, and the percent of all the interviews each type of mistake represents. For example, inadequate knowledge was mentioned as a mistake in 10 interviews, and that is 45 percent of the 22 interviews.

In this case looking at all four columns tells us that inadequate knowledge was mentioned as a typical mistake in 10 interviews and that two respondents mentioned 2 examples of inadequate knowledge when answering the question. In general, this case is representative of the following tables in that the percent mentions and percent interviews are more similar than different, but there are some tables where this is not the case.

Table 4. Mistakes in Material Selection Decisions

	Mentions		**Interviews (n=22)**	
Mistakes	*Number*	*Percent*	*Number*	*Percent*
Inadequate knowledge	12	36%	10	45%
Procedural errors	7	21	5	23
Reliance on suppliers	5	15	5	23
Goal clarity	3	9	3	14
Resistance to change	3	9	3	14
Mistakes on cost	3	9	3	14
Total mentions	33	99		

The three predominant sources of error are inadequate knowledge, procedural errors, and detrimental reliance upon suppliers. Inadequate knowledge covers such errors as the failure to understand all the functional requirements for the application in the functional environment, misunderstanding the required manufacturing process, and most often, inadequate testing. Procedural mistakes range from tackling the decision with a component rather than from a system level analysis to failing to involve the right people early in the project. Believing the salesperson about the attributes of the material or the supplier's capability are the major forms of regretted reliance on the supplier.

It is not surprising that mistakes are made, even if, as one respondent pointed out, they are usually corrected before they reach the customer. After all, myriad complex material decisions must be made in a compressed time period by numerous individuals. Nor are the sources of mistakes especially surprising. A pressured, competitive environment leads people to act rapidly, and that sometimes means too hastily, based on inadequate information and in ways that respond to short-term time pressures but undercut longer-term effectiveness. However, the reports of supplier misinformation are important because, as we shall see, the companies find themselves relying heavily on their suppliers for information about new materials.

Summary. The decision to adopt a new material or select an old one for a new application is a complicated one, involving numerous decision makers who must satisfy a wide range of constraints and goals. Consideration of a material for a particular application can arise from numerous sources, both internal and external to the vehicle assemblers. Rejection of candidate materials appears most likely to occur in the vehicle organization, although this result is probably best treated as tentative.

Strategic Goals and Structural Composites

Companies often develop policies that encourage or discourage particular types of decisions. Thus they may set a low or a high level limits on capital expenditures that can be made without specific justification to either discourage (low limit) or encourage (high limit) such investments. In 19 interviews, we asked our respondents whether their company has a policy regarding the substitution of structural composites for metals. None of them indicated that there is a specific policy covering the substitution of composites for metals. However, a number of them indicated how such decisions are shaped by other policies, such as weight reduction to improve fuel economy, drives to improve quality and lower cost, and attempts to increase recyclability. If the adoption of structural composites is not itself the target of a policy, it certainly is affected by numerous other policy initiatives. Thus fuel economy goals favor composites, while recycling goals do not.

We also asked if there are standard practices regarding the substitution of structural composites for metals that are shared throughout the company. Here respondents split, with 8 indicating there are standard practices and 8 there are not. Those who indicated that there are such practices primarily described general company processes and goals that control such decisions, similar to the comments of other respondents to the policy question discussed above.

In 20 interviews we asked what company strategic goals are the most important drivers for the adoption of structural composites. These results are displayed in table 5.

Table 5. Strategic Goals That Expand Structural Composites

	Mentions		**Interviews (n=20)**	
Applications	*Number*	*Percent*	*Number*	*Percent*
Weight reduction	12	25%	12	60%
Cost reduction	11	23	8	40
Product/process goals	11	23	7	35
Fuel economy	9	19	9	45
Customer satisfaction	3	6	3	15
Quality improvement	2	4	2	10
Total mentions	48	100		

The CAFE-driven goals of weight reduction and fuel economy together account for over 40 percent of the mentions. Moreover, in the 10 interviews that did not identify weight reduction as a strategic goal that facilitates the adoption of structural composites, we asked if it is a corporate goal and what role, if any, composites might play in it. These interviews described weight reduction as a goal, but one that was perhaps less general and more contingent on circumstances, such as moving a vehicle from one EPA weight class to another, making program goals, and the like. Six of these interviews suggested that composites might play a role in weight reduction strategies, but that they are simply one of many candidate materials, and not necessarily a candidate for major applications.

Cost reduction and product/process goals each received about one-quarter of the mentions. The cost drivers for composites include lowering investment costs, especially for low volume vehicles. The type of product goals that might expand composites applications are the increased concern for longer vehicle life, the styling possibilities that composites permit, and improved NVH (noise, vibration, harshness) performance. The process goals include part consolidation and complexity reduction.

Are there particular strategic goals at the Big Three that mitigate against the increased use of structural composites? Our respondents think there are, as indicated in table 6.

Table 6. Strategic Goals That Restrict Structural Composites

	Mentions		**Interviews (n=18)**	
Goals	*Number*	*Percent*	*Number*	*Percent*
Cost reductions	10	37%	10	56%
Timing discipline	4	15	4	22
Risk adversity	4	15	3	17
Quality improvement	3	11	3	17
Increased recycling	3	11	3	17
None	3	11	3	17
Total mentions	27	100		

These goals may operate in direct and indirect ways to restrict composite applications. Thus one respondent noted that low profits constrain internal development, and hence all programs and efforts suffer. The drive for cost reductions not only restricts experiments with untried materials, but particularly hits materials like composites, where costs have often been misestimated. The increased focus on reducing time from the automotive process, including development and launch time, works against new materials as well. Program directors are reluctant to build further uncertainty into an already complex and uncertain schedule. A general climate of avoiding risks, including potential liability, and a concern for quality leave structural composites at a disadvantage simply because the industry has less experience with them, and therefore less confidence that it can control processes that include composites.

Strategic goals do not seem to represent substantial and direct barriers to the adoption of structural composites, although the kind of subtle influences our respondents describe can be powerful indeed. Nevertheless, these goals seem less concentrated and important barriers than a variety of factors (including cost) discussed later in the report.

The comparisons of tables 5 and 6 call attention to an important aspect of the respondents' views of the situation of composites in the automotive industry today. In table 5, three interviews mention quality goals as barriers to deployment of structural composites, while table 6 reports two interviews that identify quality goals as facilitators of expanded composites application. These results highlight the fact that whether something is a barrier or facilitator depends on your view of composites and your view of the specific situation or application. Thus quality, in terms of process control may work against composites, while quality in terms of smooth shapes works for them. Moreover, respondents can and do disagree as to how much of a problem process control may be for composites.

It bears mention that our respondents here provide more information on the positive side of composites than the negative. Thus table 5 displays 48 mentions of strategic goals that are likely to facilitate the adoption of structural composites, while table 6 reflects 27 mentions of strategic goals that represent barriers to expanded composite adoptions.

This pattern of responses to open-ended questions is quite different from what we observe in response to closed questions, like the responses to our barriers and facilitators questions displayed below in tables 15 and 21. The open-end responses may reflect a habit of thinking positively about composites, while the closed-end responses suggest a recognition of the difficulties composites face, at least when confronted with inventories of possibilities.

Summary. If the automotive manufacturers lack specific policies targeting structural composites, a range of other policies influence the adoption of these materials. Weight reduction appears to be the major driver for adoption, while cost reduction poses the major restraint.

Learning about Materials

We asked a set of questions that explore the sources of information on new materials the companies utilize, and how widely held knowledge about composites for structural applications might be. The answers to these questions are important for understanding some of the issues discussed above. If uncertainty and lack of information about composites represent a significant disadvantage, then knowing where that information resides and how it is gained provide important parameters both for estimating the future adoption of composites and developing information strategies to encourage such adoption where appropriate.

In 21 of the interviews we asked how the automotive manufacturers learn about new materials and/or applications. Table 7 displays the sources identified by our respondents.

Table 7. Sources of Learning About New Materials and Applications

	Mentions		**Interviews (n=21)**	
Information Sources	*Number*	*Percent*	*Number*	*Percent*
Suppliers	20	30%	18	86%
Own research	20	30	17	81
Meetings, shows	9	13	9	43
Media	8	12	8	38
Competitors	8	12	8	38
Universities	2	3	2	10
Total mentions	67	100		

The companies' suppliers are an important source of information on new materials and applications, accounting for 30 percent of the identified sources and receiving mention in 86 percent of the interviews. Seven mentions specified material suppliers, while two specified component suppliers. This overall importance is consistent with their role in originating suggestions for new materials, discussed above and displayed in table 3. Suppliers ranked right behind component engineers as a source of suggestions for new materials. The manufacturers' own research and other internal efforts are virtually tied with suppliers as the other predominant source of learning, including advanced engineering, material labs, and the like. These two sources account for 60 percent of the identified sources.

Meetings, conventions, and trade shows were mentioned 9 times. Print media, including trade magazines, research papers, and so forth were mentioned 8 times, as was analysis of competitors, including tear-downs. These three modalities account for the remaining 40 percent of identified sources of information.

The vehicle manufacturers appear to spread their information nets fairly widely, with 30 percent of identified learning sources internal to the companies, 30 percent in the supply base, and 40 percent distributed across other external sources, including professional meetings and technical reports. Of course, these responses cannot reveal how systematically or thorough the company's actual information searches are, but it does appear that the major sources are fairly well represented.

Nevertheless, two sources might be considered notable for their low frequency. Universities were specifically identified twice, while government labs received no mentions at all. It is possible that universities and government labs might be the ultimate sources for information attributed to meetings and print media, but adding these would still suggest a rather low volume of mentions. That government labs received no mentions is somewhat surprising, because they did receive a number of mentions in other parts of the interview.

Information sources are important in the companies' general learning, but they can play a particularly important and sometimes different role when decisions are made between competing materials for a specific structural application. In each interview, we asked which sources of information respondents rely on most when making such decisions. The results are presented in table 8.

Table 8. Sources of Information for Material Selection Decisions

	Mentions		**Interviews (n=22)**	
Information Sources	*Number*	*Percent*	*Number*	*Percent*
Internal	27	52%	20	91%
Suppliers	16	31	12	55
Other outside groups	5	10	5	23
Data bases and media	4	8	2	9
Total	52	101		

The interviews most often mentioned internal sources of information for decisions between competing materials, and roughly two-thirds of those mentions stressed self-generated testing and analysis. Suppliers receive 31 percent of the nominations, as in the general learning sources results displayed in table 7. The outside groups the industry relies on for information on these material selection decisions include consultants, professional groups, and universities, while various databases and printed sources received a few mentions.

There are at least two suggestive results in the data presented in table 8. First, table 7 shows the Big Three relying upon their internal resources and suppliers to almost identical extents in learning about new materials and applications. This is in line with the comments of many industry observers that the supply base is an important source of automotive innovation, and is becoming even more important as the manufacturers focus on their core businesses and outsource responsibility in many arenas to their suppliers. However, in table 8 we see that these respondents are still more likely to rely on internal sources for information that influences the selection of materials for specific applications. This is not terribly surprising, but it does suggest that reliance upon the supply base is more comfortable and tolerable in the general information case than it is in the specific choice decision case.

Second, in the general case of information about new materials and/or applications, material suppliers are specified more often (7 mentions) than component suppliers (2 mentions). While the numbers are small, and therefore caution must be exercised to avoid over-interpreting them, we find that the split between material suppliers (5 mentions) and component suppliers (4 mentions) is much closer when the material selection decision is at issue. To be sure, material suppliers are likely to have more detailed information on the basic properties of the material; after all, they are often themselves huge companies with major research arms, while many component makers are considerably smaller and less experienced companies. However, specific applications succeed or fail based not just on the properties of the supplied material, but also on the production capability of the component or parts supplier.

In 20 interviews, we also asked respondents to comment on the general state of corporate knowledge about composites. We particularly sought to find out if that knowledge is more fact-based, or more reflective of erroneous information and belief. In a sense, this question taps the respondents' views of the general corporate attitude toward composites, and whether that attitude is based more on factual or false information. The results are displayed in Figure 2.

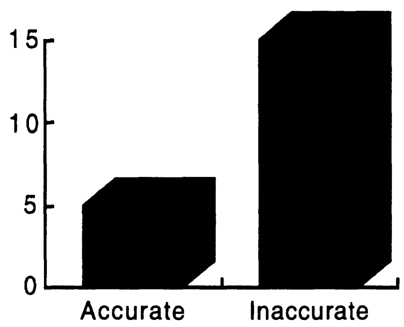

Figure 2. Perceived Accuracy of General Corporate Knowledge of Composites

Clearly, these respondents believe that much of the corporate conventional wisdom about composites is based on erroneous information. Four of the interviews particularly criticized suppliers as sources of misinformation about composites. These comments are not surprising in view of the numerous comments respondents made about supplier misinformation. These include the tendency for suppliers' promises to outstrip composites' actual performance across a wide variety of dimensions, ranging from cost to technical specifications. These results suggest that whatever the merits of the wide-net strategy for information gathering suggested in table 10, these respondents are not especially satisfied with the actual results.

We specifically asked whether most design engineers have a good understanding of composites, or whether that knowledge is more restricted to material specialists. We suspect that the widespread adoption of composites cannot occur until designers become comfortable with them, understanding them sufficiently to use them appropriately, and beginning to include them in designs at early stages. The back-up strategy, where composites are substituted on a part by part basis, typically to reduce weight, seems to us to limit composites to an occasional basis. The results of this question are displayed in figure 3, below.

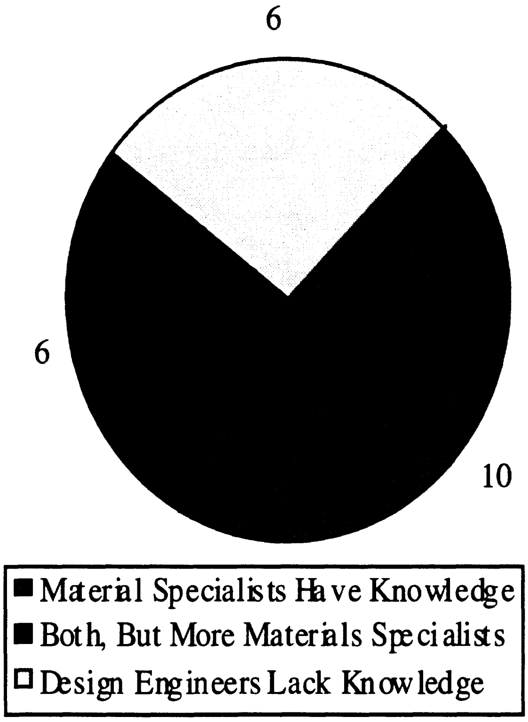

Figure 3. Location of Knowledge about Composites.

Ten respondents reported that knowledge about composites is indeed restricted to material specialists, although they express differing views on how widespread that knowledge may be within the materials community. Six respondents specifically reported that design engineers do not have a good understanding of composites. Six others commented that such knowledge is shared by some design engineers, but that material specialists have more knowledge and information. At most, then, 6 of 22 interviews indicate that design engineers may be knowledgeable about structural composites. That seems to be too few to expect composites to experience any rapid acceleration in applications in the near future.

Summary. The Big Three collect information on new materials and applications from a rather wide variety of sources, but rely primarily on their own internal resources and their suppliers, especially their material suppliers. However, when application decisions between competitor materials must be made, they are more likely to rely on their own internal resources than upon the suppliers, and to the extent that they rely on the supply base, they are likely to call upon both material and component suppliers. Nevertheless, the general level of corporate knowledge on composites is inadequate, too often reflecting erroneous information and beliefs. The knowledge that does exist within the companies is somewhat concentrated in the materials community, and probably not shared by design engineers.

The Value of Structural Composites

We explored our respondents' views on the advantages and disadvantages of structural composites through a series of questions. We first covered our respondents' own direct views, yielding a straightforward inventory of major advantages and disadvantages. We then asked them to identify specific applications particularly suitable for structural composites, and those particularly unsuitable for composites. Finally, we asked respondents to compare specifically the advantages and disadvantages of composites with those of the metals across the life cycle of the vehicle—its production, use, and retirement or disposition.

Major Advantages and Disadvantages. We first asked our respondents to tell us their own views of the major advantages of composites, displayed in table 9, and the major disadvantages, presented in table 10.

Table 9. Major Advantages of Structural Composites

	Mentions		Interviews (n=22)	
Applications	*Number*	*Percent*	*Number*	*Percent*
Weight reduction	16	31%	16	73%
Lower investment cost (at lower volume)	12	22	12	55
Part integration	7	13	7	32
Design flexibility	7	13	6	27
Corrosion resistance	5	9	5	23
Other (noise reduction, low finishing costs, etc.)	7	13	7	32
Total mentions	54	101		

There are no surprises on this list, and the advantages identified by our respondents seem to reflect the industry's conventional wisdom on the advantages of composites. The most frequently mentioned advantage is vehicle weight reduction, important because of the automakers' need to meet CAFE standards. The second most often mentioned is the investment cost advantage for low volume assembly programs, where the cost of tooling for composites is substantially below the costs for producing in steel. Nine of the 12 respondents who identified cost as an advantage commented on investment or tooling costs and/or low volume programs.

The next two are distinct but related advantages that composites confer at the design and manufacturing stages. Composites permit designers to use a wider range of more complex shapes and curves, a styling advantage over metals. This design flexibility or capability also permits designers to integrate into one part a number of parts that would have to be manufactured separately and then combined were they executed in steel. There are numerous advantages to reducing the number of parts. Part count reduction can lower manufacturing costs, improve quality, and may enhance the design. It merits mention that these combined 14 design flexibility and part integration advantages were offered by 11 different respondents, so only two offered advantages in each category. Thus, while they are related in theory, they are not automatically linked in the eyes of our respondents. Indeed, nine of them mentioned one or the other, but not both.

Corrosion resistance is, of course, a specific environmental advantage of composites over steel. The scattered mentions of advantages collected in our miscellaneous "other" category include noise reduction, long life, and strength, to mention a few. Most of these advantages seem less general, and more idiosyncratic to different applications.

If the identified advantages yield no surprises, the distribution of these advantages is not quite what one might expect. First, the 22 interviews yielded 54 mentions of advantages, about 2.5 advantages per interview. In view of this, it is somewhat surprising that only two advantages, weight reduction and investment levels at low production volume, were mentioned in the majority of the interviews, as indicated in the fourth column of table 9. Second, the respondents offered a large number of quite distinct advantages in the "other" category. While there may be a bit of a conventional wisdom about automotive composites, it appears to be neither as clear nor as shared as might have been expected.

Table 10. Major Disadvantages of Structural Composites

	Mentions		**Interviews (n=22)**	
Applications	*Number*	*Percent*	*Number*	*Percent*
Own uneasiness	16	25%	14	64%
Cost	15	23	13	59
Production suitability	12	18	7	32
Field problems	10	15	6	27
Material attributes	6	9	6	27
Recycling	4	6	4	18
Supply base concerns	2	3	2	9
Total mentions	65	99		

As displayed in table 10, the most often mentioned disadvantage of structural composites is the automotive industry's own uneasiness with them rather than any specific property or attribute shortcomings of the materials themselves. This uneasiness encompasses a lack of experience, unfamiliarity with the materials, and the need to make a paradigm shift in how one approaches the material side of vehicle design and production if composites are to increase their usage rates substantially. The lack of comfort with the industry's own general level of knowledge in the manufacturing area was specifically mentioned in four interviews.

Cost was the second most often mentioned disadvantage, virtually tied with uneasiness. Five interviews specified explicit concerns for costs in high volume production, including costs of tooling and extra steps in the molding and assembly process required for composites. Specific concerns (rather than the general ones of the uneasiness category) about the production suitability of structural composites was the third most mentioned category, including questions about paintability and their compatibility with the current assembly process, where temperatures and cycle times are largely set by and for steel. Field problems include concerns about color degradation over time and varying environments and reparability. Stiffness and lack of flexibility were the preponderant material attributes that concerned respondents.

It is rather curious that the major disadvantage of structural composites is the industry's own uneasiness with them, primarily rooted in a lack of experience and familiarity. After all, the focus of the question draws attention to the material itself, not to the industry's reaction to it. In spite of this, 14 interviews made 16 mentions of this reaction. The fact that so many respondents identified this "disadvantage" means that the mentions are not the product of just a few advocates for composites, in some sense faulting the industry for the slow adoption rate. Rather, it suggests that there is indeed a widespread reluctance and apprehension to use composites that is based on the industry's lack of experience, and therefore comfort with the materials. And this, of course, confronts the industry with a classic "chicken or egg" problem in increasing the use of automotive composites: their use will be restricted until the industry gains familiarity, but low levels of use will restrict the industry's chances of gaining familiarity.

The interpretation of the data presented in table 10 is somewhat influenced by whether one examines the distribution of mentions (columns 1 and 2) or interviews (columns 3 and 4). In particular, there are 12 comments regarding production suitability, and 6 concerning material attributes as disadvantages, but these comments come from seven and six respondents, respectively. The difference in the number of mentions suggests a difference in the importance of these disadvantages. However, the difference in the number of respondents who identified each suggests that they may be rather similar, if not in importance, at least in the number of adherents.

Suitability of Applications. We also asked our respondents to identify particularly suitable and unsuitable applications for structural composites. Responses to this question directly identify and delimit the domain of possible applications for structural composites, and indirectly say something about the respondents' views of the advantages and disadvantages they confer. Tables 11 and 12 present the suitable and unsuitable applications, respectively, coded into broad categories or subsystems of the vehicle. The detailed responses are again displayed in appendix 2.

Table 11. Particularly Suitable Applications for Structural Composites

	Mentions		**Interviews (n=21)**	
Applications	*Number*	*Percent*	*Number*	*Percent*
Body structures	15	22%	12	57%
Body components	10	14	8	38
Engine/drive train	10	14	7	33
Instrument panel/supports	6	9	6	29
Suspension	5	7	5	24
Miscellaneous parts	9	13	5	24
Generic types	14	20	10	48
Total	69	99		

We asked 21 of our respondents to identify particularly suitable applications, and they nominated, on average, just over 2.5 specific applications, rising to 3.25 if we include generic or type nominations. The most frequently identified specific applications were in body structures, with crossmembers (at 5 nominations) and bumper beams (at 3 nominations) accounting for just over half of the 15 nominations. Body components and engine/drive train applications were each mentioned 10 times, led by body panels (3 nominations) and intake manifolds (2 nominations) respectively. Instrument panels and supports were nominated 6 times, various suspension parts and components 5 times, and there were 9 nominations of miscellaneous parts and components, notably 3 for the plenum and 2 for seats.

In addition to these specific applications, respondents mentioned 14 generic requirements that they felt were particularly suited to composite applications. These included 3 nominations for applications with particular NVH needs, and 2 each for applications that would benefit from part integration or where the design requirements for other materials are complicated.

These respondents thus identified a wide range of automotive applications that are particularly suited to structural composites. However, even at the subsystem level, there is little consistency in the applications they identify. Moreover, even though they had just responded to a question about general advantages and disadvantages of structural composites, 10 respondents again identified generic advantages in addition to any specific applications they mentioned.

This pattern suggests that there is some shared feeling that there are advantages to structural composites, but little consensus on the specific applications that would be particularly suitable for them. That may be an important factor in their slow adoption rate. Agreement in principle that structural composites have utility and advantages is an important and necessary step to their adoption and deployment in the vehicle, but there must also be specific agreement that they are appropriate for a particular application before that application is adopted.

Table 12. Particularly Unsuitable Applications for Structural Composites

	Mentions		**Interviews (n=21)**	
Applications	*Number*	*Percent*	*Number*	*Percent*
Engine/drive train	9	19%	5	24%
Body structures	4	9	4	19
Body components	1	2	1	5
Miscellaneous parts	9	19	7	33
Generic types	24	51	18	86
Total	47	100		

As indicated in table 12, the engine/drive train subsystem yielded the most frequent nominations of particularly unsuitable applications for structural composites. Respondents expressed potential concern over the use of structural composites in environments with excessive heat and/or wear. Thus transmissions and internal engine applications were seen as unsuited to structural composite applications. Body structure applications were the second most mentioned subsystem. Many of the miscellaneous parts mentioned as unsuitable, such as brake parts and exhaust manifolds, are subject to heat and/or wear, the concern mentioned in regard to engine/drive train applications.

Just about half of the mentions of unsuitable applications involved generic concerns, rather than specific applications. These concerns include uncertainties about how structural composites manage energy in a crash situation, the limited temperature range they require, costs in high volume application, and their limited compatibility with today's assembly environments.

Table 13 displays the comparison of these mentions of suitable and unsuitable applications. These results suggest that body components and structures, instrument panels and suspension systems are more favorable target areas for expanded application of structural composites, while the engine and drive train offer decidedly more mixed opportunities. Moreover, if we ignore the generic category, there are 55 mentions of suitable and 23 mentions of unsuitable applications. Thus specific suitable applications are mentioned more than twice as often as specific unsuitable applications.

Table 13. Suitable and Unsuitable Applications, by System

		Mentions	
Applications	*Suitable*	*Unsuitable*	*Total*
Body structures	15	4	19
Body components	10	1	11
Engine/drive train	10	9	19
Instrument panel/supports	6	0	6
Suspension	5	0	5
Miscellaneous parts	9	9	18
Generic types	14	24	38
Total	69	47	116

However, the more important aspect of these data may be that the generic category is proportionally more than twice as large (51 percent vs. 20 percent) in the unsuitable category as it is in the suitable. This pattern admits at least two interpretations. First, it may simply reflect and reinforce the respondents' own references to uneasiness and uncertainty as a major barrier to the adoption of structural composites. These respondents are themselves more likely to fall back on generic disadvantages in describing unsuitable applications rather than identify specific ones. Second, it may simply mean that the unsuitable applications are legion, and more conveniently described in generic terms. After all, the number of parts in a vehicle that are subject to high temperature and/or wear is large indeed.

Life Cycle Comparisons. We also asked our respondents to compare the relative advantages and disadvantages of structural composites with metals, and to consider how that comparison might vary over the life cycle of the vehicle—its production, use, and retirement or disposition. This question asks the respondents to identify the specific strengths and weaknesses of structural composites compared to their major competitor materials, the metals. It also calls attention to the full life cycle of the vehicle, and thus specifically invites consideration of advantages and disadvantages that span the full range of the automakers' concern.

We coded respondent comments into three different categories: comments that were positive on composites, those that were positive on the metals (exclusively steel and aluminum), and those that suggested problems, issues, or challenges in composite usage. Our coding attempts to distinguish between comments that suggested that metals possessed an advantage (positive on metals) and those that suggested that composites possessed a disadvantage (coded as issues for composites). We make this distinction on the grounds that such comments might indicate potentially different mind sets or beliefs about composites. In particular, some automotive decision-makers may simply be more positive on metals, but consider composites as legitimate and viable potential alternatives. Others may be more negative on composites, perhaps not even willing to consider them eligible candidates for consideration. We suspect the latter mind set may be more difficult to change.[8]

These results are displayed in table 14.[9] Table 14 displays the distribution of comments rather than respondents; the distribution of respondents is essentially similar, and is displayed in appendix 2.

Table 14. Composites and Metals: Advantages and Disadvantages Across the Vehicle Life Cycle

	Life Cycle Stages			
Comments	*Production*	*Use*	*Retirement*	*Total*
Positive on composites	3	6	4	13
Positive on metal	4	1	6	11
Issues for composites	14	6	24	44
Total	21	13	34	68

A number of aspects of these results merit comment. First, comments that are positive on composites are infrequent, totaling only 13 (19 percent) across the vehicle life cycle. These comments stressed their longer life due to corrosion resistance, lower costs in low volume applications, and potentially better energy balance. Comments that note problems, challenges, and issues for composite applications are far more frequent, numbering 42, and account for 63 percent of all comments.

Second, concerns about structural composites at the production stage number 14. A number of these comments target concerns about process variability and consequent quality issues, and five address the system level issues of integrating composites with other materials in the vehicle and into a design and manufacturing process that is staffed by people familiar with steel. One respondent suggested that a vehicle made entirely of composites would avoid these problems, and might be the most effective way to expand composite usage.

Third, there are 6 comments that note issues or problems during vehicle use, and these are balanced by 6 positive comments on composites at this stage of the life cycle. Corrosion and ding/dent resistance, as well as lighter weight are seen as positives, although uncertainty about crashworthiness, and concerns about damage and appearance over time remain negatives. Although respondents directed few comments to the use stage, it is tempting to speculate that this stage is viewed as less of an issue for composite adoption than either vehicle production or retirement. The relative lack of comment combined with the balanced nature of the few comments made might suggest this is the case.

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[8]If the reader finds this argument too speculative, the comments coded as "positive on metal" may simply be combined with those noting "issues for composites."

[9]While we asked this question in 21 of our interviews, the base for table 9 is 22. We have added pertinent material from earlier responses by the omitted respondent. This material covered these issues and formed the basis for not asking this question.

Fourth, the concerns about composites are most frequent at the retirement or disposition stage, where 24 of the concerns (over half) about composites are concentrated. Each interview yielded at least one comment that was unfavorable to composites with regard to recycling, including five specifically identifying thermosets and four mentioning the lack of a recycling infrastructure for composites.

Is this widely shared—one is tempted to say universal—concern about recycling composites an absolute barrier to their use? Probably not. As one respondent put it, if a business case can be made for using composites, recycling concerns will not block it, while another suggested that recycling as a constraint is secondary to cost factors and how the material functions during the use stage of the life cycle.

Moreover, recycling is a longer-term issue. We suspect that the general question on advantages and disadvantages elicited responses that reflect respondents' view of the most important and immediate disadvantages and concerns. Thus recycling receives only 4 mentions as a composites disadvantage in table 6. Since there are relatively few composite applications currently, recycling is less of an issue than other disadvantages. However, if one considers the entire life cycle of the vehicle, specifically contrasts composites and metals, and assumes that the adoption of composites grows, then recycling may well be seen as an important future disadvantage. And, indeed, the responses in table 10 reveal a broad and shared concern about composites recycling.

Summary. If we look across the results of all of these questions that address the advantages and utility of structural composites, a few important themes emerge. First, these respondents are operating from a base of knowledge and experience. It seems clear that the respondents articulated both advantages and disadvantages of composites compared to metals, and are, as a group, neither fans nor enemies of composites. Second, the respondent's knowledge base appears to be somewhat more specific in the area of composites advantage than it is in the area of composites disadvantage. Why this might be is unclear, but the response patterns reveal more generic and somewhat less specific language when comments are directed to composites' negatives. This may suggest that wider application of composites may wait more on the resolution and reassurance on these uncertainties than on the proliferation of more information on the advantages of composites.

There is some consensus that structural composites have both advantages (weight reduction and investment cost in low volume production) and disadvantages (the industry's discomfort and cost, especially for higher volume production). There is also some agreement that they are suitable for body structure applications, as well as less frequent suggestions that they are appropriate for instrument panel and body components. However, that agreement is far from a complete consensus, since few points were agreed on by more than half of the interviews. There is markedly less agreement on automotive applications that may be unsuitable for composites, and the majority of mentions simply described generic concerns about the material. When respondents consider the full life cycle of the vehicle, then problems for composites at the retirement stage loom large.

Barriers to the Adoption of Structural Composites

The major focus of this project has been the identification and description of the barriers, if any, that have hindered the appropriate adoption of structural composites. We recognize that reasonable people may disagree deeply as to what constitutes a sensible or appropriate application of structural composites. Thus we asked our respondents to consider a list of barriers and concerns sometimes raised with regard to changes such as the adoption of structural composites. We then asked them to identify which of these are the most serious concerns, generally playing an important role in decisions against adopting structural composites.

A few caveats are in order here. First, this kind of question prompts the respondents to consider each of a series of possible barriers, rather than just volunteering those that are uppermost in their minds. In a sense, our early questions on advantages and disadvantages are like open-ended or essay questions on an exam: there are no specific clues as to what the answers may be. This question, with its offered list of barriers, is more like a multiple choice or true/false exam question: the respondent is asked to consider items that might not have come to mind without a prompt. Hence, as is often the case in the exam parallel, the responses can be quite different on the two questions from individuals or groups. Second, respondents vary in their general level or amplitude of response: some identify lots of barriers, some few. These probably reflect individual interpretations of "most serious" in the question. Third, some respondents identified many barriers as serious, but labeled a few as the most important ones, while others did not so distinguish among those they mentioned.

We display results for the general categories of barriers in table 15.

Table 15. Broad Barriers to the Adoption of Structural Composites

	Items		**Mentions**	
Barrier Categories	*Number*	*Percent*	*Number*	*Percent*
Organizational	15	33%	72	22%
Composite specific	5	11	53	16
Process	10	22	76	23
Technical	8	17	64	20
Application/use	8	17	59	18
Total	46	100	324	99

Our 22 interviews yielded 324 identifications of barriers to the adoption of structural composites, or almost 15 mentions per interview and 12 per interviewee. Even if we assume that interviewees had a tendency to identify any barriers, not just the most serious, that is a large number of barrier identifications, suggesting that the barriers to structural composites are many indeed. The interviews also yielded 31 specific identifications of barriers as "important" or "major" among those identified by respondents.

Under a random model, we would expect that barrier categories would be selected in proportion to their relative item frequency. Comparing the actual distribution of barrier nominations in column 4 with the item distribution in column 2 reveals the extent to which categories were chosen more or less often than chance would predict. Organizational barriers are chosen about 50 percent less often (22 percent versus 33 percent) than chance would predict. Process, technical, and applications/use barriers are chosen at a somewhat higher level than chance expectations, while specific barriers to composites, including cost, are just about 50 percent above the expected level.

Perhaps the most intriguing aspect of these results is that we again find that the specific barriers to composites are important, but not especially critical. They are chosen with greater than chance frequency, but that excess frequency is comparatively low. It certainly does not suggest that specific focused barriers to composites are the core barriers they face.

Moreover, these are broad categories, somewhat arbitrarily constructed and open to debate, so perhaps one should not make too much of any differences that do exist. Tables 16 through 20 present the individual barriers in each category that received 10 or more mentions (just under 50 percent of the interviews) and/or 2 or more nominations as a major barrier. The table is structured to make maximum use of the information provided by respondents, so we also include the number of nominations for most important. That requires some caution in our interpretations.

Table 16. Organizational Barriers to the Adoption of Structural Composites

	Mentions	
Barriers	*All*	*Major*
Difficulty identifying/measuring benefits/value of adoption	11	3
Difficulty of integrating new materials into existing framework	11	2
Difficulty identifying/measuring costs of adoption	8	3
Other organizational	42	0

Difficulty identifying or measuring the benefits and value of adopting structural composites was nominated in half of the interviews, and mentioned as major in 3, while the parallel difficulty in assessing costs was mentioned in 8 interviews, and again as major in 3. Difficulty integrating composites into the extant, largely steel framework, both conceptually and operationally was selected 11 times, and twice identified as major. These identifications echo comments many respondents made throughout the interview, and are not especially surprising. Rightly or wrongly, many of these respondents are not persuaded that they or their companies have a good grasp of what either the benefits or the costs of substantial adoption of structural composites would be.

Table 17. Specific Barriers to the Adoption of Structural Composites

	Mentions	
Barriers	*All*	*Major*
Total cost	14	3
Concerns about design methods and capability	13	1
Supplier capability	11	0
Concerns about lack of field data	9	2
Other composite specific	6	1

There is no question that cost in a variety of guises presents a major specific barrier to the adoption of structural composites, as indicated in table 17. Total cost was mentioned in 14 of our interviews, and three interviews identified it as major. The industry has high levels of concern about its own knowledge of appropriate design methods and capability for composites use, and the manufacturers have specific concern about the capability of the supply base, both in terms of the material suppliers and the component suppliers. Lack of field data is a barrier, and again represents a chicken and egg dilemma, since the field data will only be forthcoming in large quantities as structural composites are adopted. Of course, suppliers might develop such information before bringing materials and/or components to the manufacturers.

Table 18. Process Barriers to the Adoption of Structural Composites

	Mentions	
Barriers	*All*	*Major*
Manufacturing variability	13	1
Assembly requirements	11	0
Process time	10	1
Costs of tooling for high volume production	10	0
Other process	32	2

Process barriers cover the largest proportion of nominated barriers, and these 10 items elicited roughly one third of all the nominations they possibly could (76 nominations/10 items x 22 respondents). Respondents evidenced concerns for manufacturing variability in the production of composite parts and components (13 nominations), and the challenges of using these parts and components in the current assembly system (11 nominations), which, again, is tailored to metals. The relatively longer cycle time is a concern, as is the cost of tooling for high volume production (10 each). These results are consistent with our impressions and counts of more open ended material from the interviews: figuring out how to integrate composites effectively into a plant environment with temperatures, operations, and timing geared to steel is a daunting challenge for the composites industry.

Table 19. Technical Barriers to the Adoption of Structural Composites

	Mentions	
Technical Barriers	*All*	*Major*
Recycling	17	1
Adhesive bonding	12	2
Mechanical attachment	10	1
Material attributes	8	2
Other technical	17	0

Recycling is the most often identified barrier with 17 nominations, although only one interview categorized it as a major barrier. This seems consistent with our earlier results and interpretation: recycling is an important barrier, but it will not become operative until more proximate barriers are overcome. When composites applications are sufficiently numerous to generate large quantities of material for disposal, then recycling will indeed loom large. Joining composites with each other through adhesive bonding (12 nominations) and with metals (10 nominations) poses problems. Adhesive bonding raises issues of quality and durability, while mechanical attachments undercut the weight reduction advantages of composites.

Table 20. Application/Use Barriers to the Adoption of Structural Composites

	Mentions	
Application/Use Barriers	*All*	*Major*
Energy absorption in crash	14	2
Structural integrity in crash	10	1
Concerns about appearance	10	1
Uncertain liability for early adopters	8	2
Other application/use	17	1

Both direct and indirect concerns for the behavior of composites in a crash situation pose important barriers to their overall adoption. Thus respondents identify questions about how well composites will absorb energy in a crash (14 nomination), what their structural integrity will be in crash situations (10 nominations), and apprehension about the legal liability faced by early adopters (8 nominations). Moreover, these three concerns netted a total of 5 nominations as primary or major barriers. Finally, there are concerns about the appearance of composites, reflecting the respondents' concerns about whether composites' finishes can be painted to today's standards, and whether matching color in a repair situation will be possible.

Clearly these specific barriers can be grouped differently than we have chosen to do. Thus we coded concerns about composite material attributes as technical in table 19, but it surely could be incorporated with the specific composite barriers in table 17, just as the concern for design method in table 17 could be viewed as an organizational barrier and absorbed into table 16. Exactly how these specific barriers are best categorized and clustered depends on one's purpose. It is probably the case that the entire list of nominations, displayed in appendix 2, should be reviewed before any specific analytic or programmatic decisions are made.

Summary. The barriers to structural composites are numerous and diffuse. Unfortunately, they do not form a coherent set that can be readily targeted and resolved, or, if necessary, compensated in some way. Rather, they are dispersed throughout the entire range of experiences and decisional considerations that our respondents describe. Nevertheless, it is clear that process, recycling, cost, and safety concerns are among the major barrier themes.

Facilitators of Structural Composite Adoption

We also asked whether there were any factors or aspects of structural composites that were especially favorable and therefore likely to accelerate their adoptions. We asked about seven general facilitators and 11 that are more specific to structural composites. The results for facilitators mentioned in ten or more interviews are displayed in table 21.[10]

Table 21. Facilitators of the Adoption of Structural Composites

	Mentions	
Facilitators	*Number*	*Percent*
Clear evidence of cost/benefit of adoption	20	14%
Vehicle objectives for weight reduction	16	11
Vehicle objectives for fuel economy	16	11
Vehicle objectives for cost reduction	15	11
Design attributes	12	8
Low costs for low volume production	12	8
Other	51	38
Total	142	99

The interviews yielded 142 total mentions of facilitators, or just about 6.5 per interview and just over 5 per respondent. This is just over 40 percent of the number of mentions of barriers, discussed in conjunction with table 13 above. However, we inquired about more barriers (46) than facilitators (18), and that may partially account for the difference, since more prompts elicit more responses. Nevertheless, it is also the case that respondents often find it easier to discuss positive material than negative.

There is another interpretation for these comparative mentions of barriers and facilitators, and that is that we seem to focus more on barriers than facilitators when approaching a change situation. Thus our list of these two factors differed because the literature on change identifies more barriers than facilitators. Our earlier work on technology transfer and learning between the Big Three and their Japanese cooperators found a similar pattern of more frequent mention of barriers than facilitators. The differences in that situation are even more dramatic than the ones reported here.[11]

It is important to note that our respondents almost invariably turned this question on facilitators into a hypothetical one, and discussed factors and developments that might, if they came to pass, expand the automotive application of structural composites. Thus, if clear evidence of the cost/benefit of composite adoption were to emerge, composite adoption would accelerate. Similarly, if structural composites contributed to obtaining vehicle objectives for cost reduction, that would greatly facilitate their adoption.

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[10]Only three facilitators were identified as of major importance compared to others mentioned, so we eliminate this aspect of the analysis.
[11]Michael S. Flynn and David J. Andrea, Corporate learning from Japan: Partnering, People, and Process Technology, UMTRI Report #93-42, (Ann Arbor, MI: University of Michigan Transportation Research institute, December, 1993).

Our respondents affirm that meeting vehicle objectives for weight reduction and fuel economy are the current major drivers for expanded adoption of structural composites. These objectives are both rooted in the need to meet CAFE standards, and that raises an issue. In the view of most of the automotive community, CAFE standards are an inefficient way to achieve fuel conservation that improperly and unfairly burdens the companies with the responsibility for implementing national policy and often sets them at odds with their customers. In other words, the major drivers for structural composites lie in a resented government interference rather than in any automotive advantages such materials might offer. We suspect that there is somewhat a feeling of "I'll use them because I have to, but I don't have to like them." That is, composites are a necessary evil, foisted upon the automotive community, rather than a material with attractive attributes and potential value for automotive application. Might not such an attitude deter the industry from working to improve and expand structural composite applications, at least until they see automotive advantages for using them? We think that is likely the case.

Design attributes and low costs for low volume production were each identified as facilitators by 12 respondents. The cost advantages of structural composites in low volume production suggest one possible path to expanded composite usage. Many analysts believe that average production volumes per model will keep falling, as market factors continue to pressure for a more differentiated and segmented market, while technical and process developments increasingly make such a market feasible. If the market does become more and more one of niche vehicles, then the future of composites will likely be brighter, since the industry generally feels that these materials have an overall cost advantage in low volume production.

Summary. There are important facilitators for the adoption of automotive structural composites, including the general CAFE-inspired goals for weight reduction and fuel economy, and more specific goals met by their design attributes and lower costs in low volume production. The CAFE-related goals may foster resistance, but market developments may strengthen the importance of composite advantages for low volume vehicles.

Effective Steps to Wider Composites Deployment

We asked a few questions that address the issue of how applications of structural composites might be appropriately expanded. In 16 interviews we asked that the respondents consider the past history of the company, and suggest what—if anything—might have been done differently to facilitate the rate and/or effectiveness of structural composite adoptions.[12]

Four of these interviews suggested that time ought to have been compressed and activities, from research into the development of new applications for material to pilot programs, begun earlier. Four others suggested organizational strategies for allocating people to tasks, from early involvement of everyone connected to the product to developing composite design capabilities. Three suggested that a clearer strategy around weight reduction, especially placing a higher and specific value on component weight reductions, would have accelerated the adoption of composites, while two stressed the need for leadership at the top or in the technical areas. Three suggested that there really

[12]This question appeared late in the interview. Consequently, it was not asked in some interviews because of limited remaining time, while in others it was eliminated because the respondent had already made comments to the issue.

was nothing that the company should have done differently, implying that the adoption rate has been about right. One interview turned the question around, and suggested that composite supporters must get beyond the denial stage, and recognize the need to address basic problems and difficulties with composites.

In eight interviews, we also asked about barriers—what might have been done differently to overcome or avoid the barriers to appropriate adoption. Responses here were also fragmented, ranging from more research on composites to a slower pace of introduction, which might have lessened the number of failures. These comments on both facilitators and barriers are interesting, but their overall importance may be more in suggesting that the problems composites adoptions have encountered have been somewhat diffuse, or, at least, the strategies for responding to them are probably complex.

In all of our interviews we asked what are the most effective steps the automotive composites industry could take today to facilitate the structural applications of composites. In 21 of our interviews we also asked respondents to imagine they worked at a resin manufacturer, or a composites component supplier, and to identify the one or two critical initiatives they would encourage the company to pursue to enhance the application rates of structural composites. Our original intent was to see if this latter question, targeted to the company level, would elicit different strategies than those elicited by the prior question, targeted to the industry level.

There are differences between the types of responses the two questions elicited, but they are few in number. A few respondents simply reiterated their earlier remarks in responding to the second question, but most took the opportunity to expand them. Therefore, we have combined the responses to these two questions, eliminating simple repetitions, but including additional information from the same interviews. We summarize these combined suggestions in table 22, and again provide detailed information in appendix 2.

Table 22. Effective Industry Steps to Expand Use of Structural Composites

	Mentions		Interviews (n=22)	
Steps	*Number*	*Percent*	*Number*	*Percent*
Demonstration projects	21	27%	16	73%
Process improvements	14	18	9	41
Information efforts	14	18	6	27
Recyclability	6	8	6	27
Improved modeling	6	8	5	23
Product improvement	6	8	5	23
OEM/supplier relations	5	6	4	18
Other	6	8	4	18
Total	79	101		

These interviews strongly suggest that demonstration projects are likely to be the single most effective step for accelerating the application of automotive structural composites. Just over 25 percent of the mentions and nearly 75 percent of the interviews suggest this strategy. Unfortunately, demonstration projects form a focused, targeted strategy only at a fairly broad level of generality, since the specific demonstrations the respondents suggest cover a wide range of activities.

These recommended demonstration projects include nine quite general efforts, such as discovering the most successful applications and building the general business case and targeting a segment and show composites can compete with metals successfully. They also include 10 more specific demonstrations of potentials like part integration and developing effective crash absorption systems. Two of these suggestions are targeted to the Automotive Composites Consortium (ACC): design and build a composite vehicle that can be built at high volume, and create a "business unit" to develop and manufacture a frame. Two suggestions also call for cooperative, cross-company efforts. One targets funding dual-path programs at the manufacturers to ensure exploration of composites, while the other suggests establishing "take back" programs to address the vehicle manufacturers' concern about recycling.

Suggested process improvements primarily include reduced cycle times and increased process control for material consistency and quality. The information efforts, like the demonstrations projects, are rather diffuse at the level of specifics. They range from suggestions to build a composite database to specifications of what it might contain, supplemented by requests for the creation and adoption of standards throughout the composites community. These standards, in turn, need to cover language and test methods, and procedures. One respondent expressed hope that the ACC's activities would lead to benchmarking. It bears mention that these efforts address reducing unknowns and industry uncertainties, rather than adding more positive information on composites.

Enhanced recycling of structural composites is mentioned 6 times, with one respondent recommending that the composites industry divert some of its public relations funds on recycling to fund a program on composites recycling at the national labs. The 6 suggestions for improved modeling primarily target the safety concerns raised at various places in this report. Product improvements target lowering cost and achieving consistency in the material.

A number of suggestions focused on the relationship between the manufacturer and supplier. One respondent called for the composites industry to devote resources to developing low risk applications in consort with the vehicle manufacturers. Another suggested the composites industry should invest in training designers in the use of structural composites so the industry builds its design experience and capability with the material.

Finally, a number of suggestions do not fit into even these loose categories. One suggested, in stark contrast to the suggestion with regard to recycling above, that the industry should work on its own and its product's image, turning the currently somewhat negative perception around. Another suggested that the composites industry needs to more realistically address its own shortcomings, analyzing their sources and working to overcome them. One interviewee suggested that the composites industry ought to work more closely with the Automotive Composites Consortium, since that group really does represent the Big Three's common interests.

In closing, we asked our respondents if there were any questions we missed in our interview, or if there was any important information they had not told us. Most respondents used this opportunity to summarize or to highlight their earlier remarks, and these responses emphasize some of the comments that were scattered throughout the interview, often in different places, by numerous respondents.

First, the competitive environment does not support wide experimentation with and try outs for new materials. The industry is too cost conscious to undertake such efforts lightly, and too concerned about quality and customer reaction to adopt unknowns. Risk-adverse environments do not spawn innovations.

Second, in the view of most respondents, composites are definitely tracking behind the metals—especially aluminum—as lighter-weight alternatives to steel. This is partially based on familiarity and prior experience, partially on aluminum's recyclability.

While it may require a paradigm shift in industry thinking and operational behavior for composites to make major inroads, the composites industry dare not assume that this means the only problem is a stodgy, change-resistant automotive industry. The general flow of dialogue has too often been, "Here's a wonderful material, why don't you use it." The composites industry has not mastered all application problems, so it is not just the industry's "Not-Invented-Here" syndrome that is preventing structural composites from sweeping steel into the scrap bucket of history.

Finally, there are widespread serious concerns about the costs of composites. In today's environment, materials that are not cost competitive have to have overwhelming advantages—like aluminum's recyclability—to be seriously considered for applications. No one sees such advantages in composites, except for weight reduction. And that advantage is more limited and less specific to composites than might seem to be the case.

Strategic Approaches

This report makes it clear that there is no one barrier, whether real or imagined, to the adoption of structural composites. Nor is there one simple and straightforward strategy or tactic that can function as a quick fix and assure the rapid and full deployment of structural composites throughout the automotive industry. Rather, effective strategies will combine different elements targeted to different problems into a coherent and complementary program. While the full development of such a strategy is beyond the resources and capabilities of this project, we have some observations that may assist in the development of such a strategy.

A fundamental issue facing the composites industry is whether or not a strategy of gradualism can be effective. On the positive side, the cost and quality competitive concerns discussed throughout this report certainly suggest that the manufacturers are more likely to adopt structural composites in a limited application, where cost and quality can be better controlled. Incremental adoptions also permit the industry to slowly build its technical and human capabilities in this area, rather than requiring substantial and rapid acquisition of new technology and skills.

However, composites face a major hurdle in continuing to be the odd material in a system of thinking and building that is focused on and tailored to steel. This often has required compromises in manufacturing and product design that undercut whatever advantage composites offer. Fasteners can reduce the weight advantage, and deformation due to heat can escalate costs enormously. Gradual adoption of composite components may simply ensure a continuing string of disappointing experiences, building more and more resistance to their future use.

The dilemma for encouraging composites use is a stark one. Gradualism permits a doable program, but risks losing advantages and taking on disadvantages to such an extent that the chances of failure are seriously increased. A revolutionary program like an all-composite car permits maximizing advantages and minimizing disadvantages to increase the chances of success, but such a program may not be doable.

We suspect that this stark choice—painfully slow gradualism versus rapid revolution—is somewhat artificial, and that there are components and parts that offer a range of midway alternatives. That is, there probably are parts that are substantial enough to attract attention in the automotive community, sufficiently insulated in production, and advantageous when executed in composites, but still affordable in today's climate. The pick-up box, frames, and door structures may be examples of such opportunities.

Composites have proven cost effective in low volume applications, and there is both a risk and an opportunity in that situation. The risk is persuading the auto industry that low volume production experience has any bearing on high volume production. That is, the comparative advantage of composites in niche production may limit it to such applications. The opportunity is that market dynamics may expand the frequency of lower volume vehicles to the point that automakers regard many more vehicles as suitable for composites applications.

There is a substantial question whether any one company can undertake the risks inherent in a serious exploration of structural composites, even short of a complete composite vehicle. This suggests that a consortium made up of automakers, resin producers, and molders might be a useful way to provide the capital and human resources necessary for such an effort. The Auto-Steel Partnership was formed to encourage the use of steel and to beat back a perceived challenge from thermoplastics in the 1980s. This may provide a useful model for the composites industry. One aspect of this consortium deserves careful consideration by the composites industry: It puts the material supplier in direct contact with the automaker. In the composites industry, material suppliers are often highly competent, but component suppliers may be quite a bit less competent, so the material suppliers may be better positioned to work with the manufacturers.

Safety concerns are an important source of resistance to structural composites and the complete composite vehicle. It may be that a consortial effort would usefully be directed toward developing, testing, and validating in the field analytic models for the behavior of composites across different stress, crash, and crush situations. Other consortial efforts might include developing industry standards through SAE and material suppliers funding vehicle-manufacturer and component-supplier training and education through AIAG, ASI, SAE, etc.

We suspect that recycling concerns will only become more substantial and significant barriers to structural composites as time passes. Evaluating life cycle environmental impacts and seeking more recyclable composites may both be appropriate consortial activities.

Marketing of composites has been problematic: The automotive customer feels oversold and underdelivered on their promises and prospects. That may suggest that broader marketing efforts from the material suppliers might better come through the R&D and engineering functions than through the sales function.

Above all, the composites industry should recognize the reality of past problems in implementing structural composites in automotive production, and avoid patronizing and insulting potential customers. Nevertheless, conceptual habits and operational investments are sources of resistance to composites applications in the automotive industry. The composites industry needs to recognize them as pragmatic concerns and target them as any other barrier. The composites industry benefits little from an approach that primarily complains about such attitudes.

Appendix 1: Interview Guide

Structural Composites in the Automotive Industry

A Project of
The Office for the Study of Automotive Transportation
University of Michigan Transportation Research Institute
For
The Automotive Composites Consortium

Michael S. Flynn	Brett Smith	Al Horsmon	Bruce Belzowski
Associate Director	Res. Associate	Sr. Eng. Res. Assoc	Research Assoc.
OSAT	OSAT	Marine Systems	OSAT

OSAT is conducting research, funded by the Automotive Composites Consortium, designed to develop a better understanding of the material adoption process as it relates to structural composites.

For our purposes, composites are fiber reinforced polymeric materials, and structural and semi-structural applications cover a wide variety of demanding and high stress applications. These include body components like body sides, front end structures, cross-members, floor pans, and pickup boxes; suspension components such as linkages and leaf springs; bumper components such as beams and supports; interior components, like seat back/frame parts and instrument panel supports; drive shafts; wheels; and engine applications such as intake manifolds, rocker arm covers, and water pumps. However, we do exclude body panels from consideration in this study, unless they are integrated into the body structure.

Our primary objective is to identify the critical barriers to and facilitators of the industry's application of structural composites and to identify the critical factors that underlie that process. Our method relies upon interviews with participants in this material selection process from each of the Big Three. We recognize that many of our questions ask for your own views and experiences, and we do not consider you to be speaking for Ford.

The interview seeks general information on the overall material selection process only to the extent that it sets the context for adoption. Our study focuses on how the industry makes these decisions, and how that has influenced the rate of adoption of structural composites. While we recognize that each decision is in some sense unique, we are trying to identify the parameters and concerns that are shared by most such decisions.

Your responses will be treated confidentially. Your specific responses will be known only to the research team at UMTRI, and will not be released to anyone else. We would identify you as the source of a particular comment or observation only with your permission. We are sensitive to the need to treat information such as this with special care. Finally, our interest is to help the process of innovation and adoption, not to critique the efforts of any one company nor to compare them with others.

I. General Background

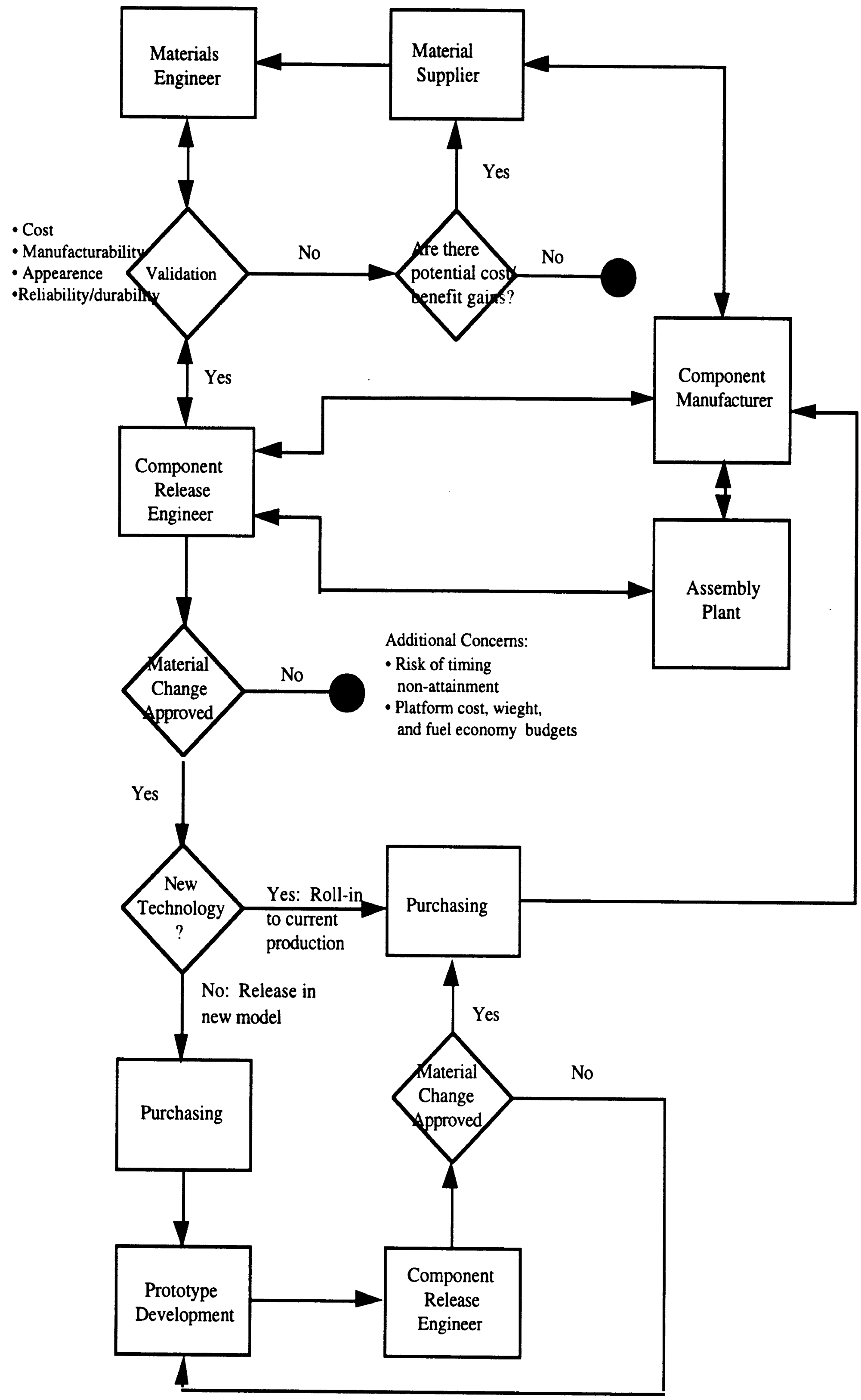
This section focuses on some overview material on the material selection process and your views of the comparative value of structural composites and metals for automotive applications. This is so we understand the context for the material selection issues that our study targets.

1. Here is a simplified flow chart of the automotive materials selection process. (See Figure 1) Is this a reasonable description of the process here at (Ford, GM, Chrysler)?

a. In your experience, where does the suggestion for a material change, such as the substitution of structural composites for metals, typically originate? Where is such a suggestion most likely to start?

b. Where does the decision to reject proposed adoption typically occur? Who is most likely to veto?

FIGURE 1



The Automotive Materials Decision Process (Andrea and Brown, 1993)

2. What do you see as the major advantages and disadvantages of structural composites?

a. For what, if any, applications are structural composites particularly suitable?

b. For what, if any, applications are structural composites particularly unsuitable?

3. Broadly speaking, how would you compare the advantages/disadvantages of composites compared with metals across the life cycle of the vehicle—its production, use, and retirement or disposition?

4. Have you experienced situations where your company adopted or rejected structural composites, and later, in retrospect, viewed that as an unfortunate decision—perhaps even reversing the decision with a subsequent program?

a. Why or how did this happen?

II. Adoption

This next section focuses on how structural composites may—or may not—be adopted for application. We are particularly interested in the barriers to and facilitators of structural composites applications that you think have existed in your company.

5. How widespread is knowledge about composites for structural applications—do most design engineers have a good understanding of these materials, or is that knowledge more restricted to material specialists?

a. Please consider the general level of corporate knowledge about structural composites—how much of it is fact-based, and how much perhaps reflects perceptions based on erroneous information and beliefs? In other words, how accurate is the "conventional wisdom" on structural composites?

6. In general, how does your company learn about new materials and/or applications?

a. What are the typical sources of information?

7. When you make decisions between competing materials—aluminum or steel versus composites, for example—for a particular structural application, what sources of information do you typically rely on most?

8. Here is a list of barriers and concerns sometimes raised with regard to changes such as the adoption of structural composites. (See Figure 2). Which of these are the most serious concerns, generally playing an important role in decisions against adopting structural composites?

FIGURE 2
POTENTIAL BARRIERS TO ADOPTION

Organizational Issues
Difficulty of identifying and measuring benefits/value of adoption
Difficulty of identifying and measuring costs of adoption
Difficulty of integrating new materials into existing framework
General company resistance to new ideas or practices from outside (NIH)

Inadequate communication of benefits to appropriate organizational units
Inadequate funds and/or time for adoption
Individual career concerns: developing new and wasting old knowledge
Lack of identifiable "champions" for specific changes
Learning/adoption undercut by pressure to operate business as usual
Narrow focus of adoption decisions ("cherry-picking", "quick fix")

Resistance by union
Resistance of specific engineering groups
Resistance to bringing new and unfamiliar suppliers on-line
Shifting emphasis on different adoption targets ("material of the month")
Strong company culture that preserves the status quo

General Composite Issues
Concerns about design methods and capability
Concerns about lack of field data
Raw materials purchase costs
Supplier capability
Total cost

Processing Issues
Assembly requirements
Costs of tooling for high volume production
Environmental discharges
Labor intensity
Lack of production experience
Manufacturing variability
Processing costs
Process time
Quality control challenges
Worker protection

Technical Issues
Adhesive bonding
EMC/RFI compatibility

Flammability

Heat tolerance
Material attributes: modulus, strength, thermal expansion, etc.
Mechanical attachment
Recycling

VOC release

Application/use Issues
Concerns about appearance
Concerns about consumers' perceptions of implied "quality"
Durability

Energy absorption in crash
NVH performance

Reparability
Structural integrity in crash—impact protection, low car mass
Uncertain liability for early adopters

9. Here is a list of general facilitators of the adoption of new practices and materials, combined with specific advantages sometimes attributed to structural composites. (See Figure 3). Which of these are the most important facilitators and advantages, generally playing an important role in decisions to adopt structural composites?

FIGURE 3

FACILITATING ATTRIBUTES

General

Clear evidence of cost/benefit of adoption
Clear, high level champions
Ensuring against negative individual consequences of learning/adoption
Individual career rewards for learning/adoption

Involvement of appropriate key personnel in learning/adoption process
Permitting sufficient time for learning/adoption processes
Sufficient resources

Structural Composite Specific

Design attributes
Formability
Improved NVH
Long life

Low costs for low volume production
Nonmagnetic, nonconductive, low electromagnetic interference
Specific strength
Vehicle objectives for corrosion and rot resistance

Vehicle objectives for cost reduction
Vehicle objectives for fuel economy
Vehicle objectives for weight reduction

III. Lessons Learned

This section focuses on how you would change the process if you again faced a major task of material learning and adoption. In a sense, what are the lessons you have learned about such adoptions?

10. Does your company have a policy regarding the substitution of structural composites for metals?

a. If not, are there standard practices that are shared throughout the company?

b. How are these policies or practices communicated from one program to another?

11. What are the typical mistakes companies make in material selection decisions?

a. What—if anything—might your company have done differently to facilitate the rate and/or effectiveness of structural composite adoptions?

b. How about barriers—what might you have done differently to overcome or avoid the barriers to appropriate adoption?

12. What, if any, are the strategic goals in your company that are the most important drivers for the adoption of structural composites?

a. Is weight reduction an important goal?

b. What role, if any, do structural composites play in your strategies for weight reduction?

13. What, if any, are the strategic goals in your company that are the most important barriers to the adoption of structural composites?

14. What are the most effective steps the automotive composites industry could take today to facilitate the structural applications of composites?

a. If you worked at a resin manufacturer, or a composites component supplier, what are the one or two critical initiatives you would encourage your company to pursue to enhance the application rates of structural composites?

Are there any major questions about the adoption of structural composites that we haven't asked? Is there anything you think we should know that we have not covered?

THANK YOU

Appendix 2: Detailed Results, by Table

Table 3. Identified Material Decisions, by Process Stage

Origination	**Subtotals**	**Totals**
Component Engineer		9
Component engineer	3	
Release engineer	3	
Component release engineer	2	
Product engineer	1	
Supply Base		8
Materials Engineer		5
Advanced Functions		5
Advanced organizations	2	
Program assumption	1	
Materials research	1	
Engineering	1	
Team/program		2
Total		29

Rejection	**Subtotals**	**Totals**
Team/program		16
Program office/platform team	10	
Design release manager	2	
Cross-function team	2	
Development team	2	
Component Engineer		5
Component release engineer	5	
Manufacturing		2
Manufacturing engineer	2	
Advanced Functions		1
Materials Engineer		1
Total		**25**

Table 4. Mistakes in Material Selection Decisions

	Subtotals	Totals
Inadequate Knowledge		12
Inadequate testing	5	
Not understanding all the functional requirements in the functional environment(e.g. lack of understanding of variability in the manufacturing process)	2	
People not familiar with materials making the decisions	2	
Not enough knowledge about the entire process	1	
Assuming prototype success means production success	1	
Overly optimistic assumptions about what you can do	1	
Procedural Errors		7
Selecting materials before design	1	
Short view	1	
Component versuss system mentality	1	
Not getting the right people on board early on	1	
Doping a high risk project without a backup	1	
Going into production without a proven validation plan	1	
Not providing enough training to make an option successful	1	
Reliance on Suppliers		5
Believing the salesperson	4	
Supplier capability	1	
Goal Clarity		3
Not having the customer up front. There has to be an identified need or want from the user	1	
Beginning without requirements	1	
Unwilling or unable to transfer the voice of the customer to the product or manufacturing process	1	
Resistance to change		3
General reluctance to change	2	
Alternative materials more costly, so difficult to change	1	
Costs		3
Design costs, variable cost as opposed to total costs	2	
Underestimated costs	1	
Total		**33**

Table 5. Strategic Goals That Expand Structural Composites

	Subtotals	Totals
Weight Reduction		12
Product/process Advantages		11
Value of long life	3	
Part consolidation	2	
Styling	1	
Robustness	1	
Improved NVH	1	
Complexity reduction	1	
Repeatability	1	
System improvements	1	
Cost		11
Drive investment cost down	3	
To become a low cost manufacturer and "meet" expectations of customers	2	
Low investment for low volume vehicles	2	
Cost	1	
Variable cost	1	
Total costs	1	
Program costs	1	
Fuel Economy		9
Customer Satisfaction		3
Quality Improvement		2
Total		**48**

Table 6. Strategic Goals That Restrict Structural Composites

		Subtotals	Totals
Cost			10
	Cost	5	
	(Lack of) ability to make a profit saps internal development	1	
	Investment efficiency	1	
	Variable cost and development costs	1	
	Budget/manpower	1	
	Facility utilization, commonization	1	
Timing			4
	Timing	2	
	Development time	1	
	The demand that all startups be smooth and all timing be smooth	1	
Risk Adversity			
	4		
	Risk adversity	3	
	Potential liability	1	
Recycling			3
Process Variability Reduction for Quality			3
	Process variability reduction for quality	1	
	Want all quality to be 100%	1	
	Uncertain quality (C8B)	1	
None			3
Total			**27**

Table 7. Sources of Learning About New Materials and Applications

	Subtotals	Totals
Suppliers		20
Suppliers	11	
Material suppliers	7	
Component suppliers	2	
Own Research Efforts		20
Internal research efforts	7	
Advanced engineering	5	
Materials lab	4	
Tech clubs /communication between teams	2	
Employee ideas	2	
Professional Meetings or Trade Shows		9
Media		8
Trade magazines	5	
Tech papers /research papers	2	
Media	1	
Competitors		8
Universities		2
Total		**67**

Table 8. Sources of Information for Material Selection Decisions

		Subtotals	Totals
Internal			27
Self-generated information testing/analysis		11	
Internal experts		4	
Material engineer		4	
Competitive analysis		4	
Other		4	
Tech clubs	1		
Cross-functional team	1		
Manufacturing process information	1		
Design engineer	1		
Suppliers			16
Suppliers		7	
Material suppliers		5	
Component supplier		4	
Other Outside Groups			5
Consultants		2	
SAE/ASM standards		1	
Universities		1	
Associations		1	
Data Bases and Media			4
Materials Databases		1	
Library		1	
Magazines		1	
Literature from government		1	
Total			**52**

Table 9. Major Advantages of Structural Composites

	Subtotals	Totals
Weight Reduction		16
Lower Investment Cost at Lower Volume		12
Lower investment cost at lower volume	8	
Low tooling investment for low volume	4	
Design Flexibility		7
Design flexibility and complexity	4	
System opportunities for complexity reduction	1	
Properly engineered, more robust systems	1	
Smooth shapes	1	
Better Integration of Parts		7
Corrosion Resistance		5
Other		7
Noise reduction	2	
Acceptable cycle time	1	
Useful life	1	
High strength	1	
Low finishing costs	1	
Energy management	1	
Total		**54**

Table 10. Major Disadvantages of Structural Composites

		Subtotals	Totals
Uneasiness, Discomfort, Lack of Experience			16
Unfamiliarity/Discomfort/Paradigm Shift/		8	
Fear of unknown/Lack of confidence	2		
Testing difficulties	2		
Crashworthiness hard to model	2		
No database of materials	1		
Not enough background/trust with material	1		
Unknown manufacturing		4	
Risk		2	
Liability		1	
No proven applications in structure		1	
Cost			15
Cost , undifferentiated		6	
Cost disadvantage for high volumes		4	
Investment in tooling for high volume	2		
Total part cost disadvantage		1	
Raw materials costs		1	
Added manufacturing costs		3	
Production Suitability			12
Paintability		3	
Dimensional stability		2	
Temperature control due to changes in heat		2	
Joining/Adhesives/Attaching		2	
Process variation		1	
Compatibility with assembly process		1	
High cycle times		1	
Field Problems			10
Material degradation over time		5	
Material degradation over time	2		
Color /Color mismatch	2		
Environmental effects like heat	1		
Quality/failure mode problems		2	
Reparability		1	
EMC/EMI		1	
Customer negative feeling of "plastics"		1	
Material Attributes			6
Stiffness/Flexibility		3	
Damagability		1	
Strength/durability		1	
Variability of performance		1	
Recyclability			4
Supply Base Concerns			2
Total			**65**

Table 11. Particularly Suitable Applications for Structural Composites

		Subtotals	Totals
Body Structures			15
Crossmember		5	
Bumper beams		3	
Floor pan /Platform		3	
Load floors, pick-up truck beds		2	
Front longitudinal rails, sun roof frames (1 each)		2	
Body Components			10
Body panels		3	
Body		2	
Rear Shelf		2	
Door Panels, complete exterior skin, spoilers (1 each)		3	
Engine/drive Train			10
Intake manifolds		3	
Drive shafts		2	
Cooling modules, valve covers, radiator cross member, shift forks, transmission cases (1 each)		5	
Instrument Panel/Supports			6
Suspensions			5
Suspension members		2	
Leaf springs		2	
Shocks		1	
Miscellaneous Parts			9
Plenum		3	
Seats		2	
Bracketing, battery trays, brake and clutch pedal support, front wiper module housing		4	
Generic Types			14
Low volume applications		3	
With unique NVH needs	2		
Low tooling costs	1		
Where design is complicated or circuitous		2	
Integrate parts		2	
Small parts that are not labor intensive, crush structure, dimensional stability with no worry of surface, where you can reduce weight in cost/lb, pure structural parts that are not visible, bolt-on parts, trim (1 each)		7	
Fun			
Sailboats		1	
Total			**69**

Table 12. Particularly Unsuitable Applications for Structural Composites

	Subtotals	Totals
Engine/drive Train		9
Transmissions	3	
Drive shafts	2	
Engine (internal)	2	
Cradle	1	
Powertrain	1	
Body Structures		4
Door beams	1	
Front & rear structure	1	
Longitudinal rails	1	
Side structure	1	
Body Components		1
Exterior vertical panels	1	
Miscellaneous Parts		9
Chassis/frame	2	
Brake rotors	1	
Brake systems	1	
Control arms	1	
Exhaust manifolds	1	
Fascia systems	1	
Steering	1	
Wheels	1	
Generic Types		24
Crash structure problems	5	
Low temperature limits	4	
Cost in high volume applications	3	
High contact stresses / highly stressed parts	2	
Process limitations	2	
Dynamic applications	1	
Functional parts	1	
Heavy structural parts have no weight advantage	1	
Interior sections visible to the customer	1	
Joining/structural adhesive problems	1	
Replace flat sheets of material	1	
Where flexibility is an issue	1	
Where parts have heavy wear	1	
Total		**47**

Table 14. Composites and Metals: Advantages and Disadvantages Across the Vehicle Life Cycle

Production

	Subtotals	**Totals**
Positive on Composites		3
Investment in tooling for composites in less for low volume	2	
We think we can do low cost composites by 2000	1	
Positive on Metals		4
Ferrous metals are cheapest	2	
Metal design and manufacturing is better understood	1	
Steel has low risk	1	
Issues for Composites		14
Trouble attaining quality through process control	2	
Composites have repeatability and consistency questions	2	
Failure mode hard to predict	1	
Composites are an unknown with production joining in high volume	1	
Composites must be injectionable. New polycycles may be the future	1	
Need to increase predictability of molding process for composites	1	
Cycle time, for composites needs to be less than a minute or you will run out of money and space	1	
I would like to create a complete composite assembly, with class A finish, get out of structural category into total system. Then we wouldn't have to dress the car out with other materials.	1	
Biggest problem is overall vehicle manufacturing process to support plastic composites	2	
We don't have engineering talent to optimize the design of composites, so we are dependent on suppliers	1	
Difficult to integrate composite into assembly plant with minimal effect and cost on a high volume basis	1	
Total		**21**

Use

	Subtotals	Totals
<u>Positive on Composites</u>		6
Composites are corrosion resistant and give long life	3	
Weight	1	
Composites the same as steel	1	
Painted composites - no rust from chips, probably less prone to ding/dent	1	
<u>Positive on Metals</u>		1
Fuel energy saved offsets any increase in manufacturing energy	1	
<u>Issues for Composites</u>		6
Composites have damagability problems	1	
Crashworthiness is hard to model with composites	1	
Composites tend to lose color and lose paint	1	
Composites have no intrinsic advantage for customer	1	
Composites have a reliability challenge because of need for testing and tolerance for abuse	1	
Painted composites replacement probably more costly	1	
Total		**13**

Retirement

	Subtotals	Totals
<u>Positive on Composites</u>		4
Composites are less energy intensive to recycle	1	
Composites can be re-conditioned and re-used	1	
Over the lifetime of the composite, it saves energy. You save weight, save fuel, and recover some of the energy used.	1	
The total environmental impact is not as bad for composites as steel	1	
<u>Positive on Metals</u>		6
Steel has high recyclability	3	
Metals are easy to recycle	1	
Aluminum wins hands down over composites for recyclability even if it costs less to use composites	1	
Metals can be re-used in same applications; composites can't	1	
<u>Issues for Composites</u>		24
Recyclability a problem with composites	11	
Thermosets have poor recycling	5	
No infrastructure for recycling	4	
More an issue with composites	2	
There will be incentives for us to reduce composites	1	
Adhesives may be a problem with disassembly	1	
Total		**34**

Tables 16-20. Potential Barriers to the Adoption of Structural Composites

Organizational Issues	Totals/Most Serious Barriers
Difficulty of identifying and measuring benefits/value of adoption	11/3
Difficulty of integrating new materials into existing framework	11/2
Difficulty of identifying and measuring costs of adoption	8/3
Inadequate funds and/or time for adoption	8/0
Learning/adoption undercut by pressure to operate business as usual	6/0
Resistance of specific engineering groups	6/0
General company resistance to new ideas or practices from outside (NIH)	4/0
Lack of identifiable "champions" for specific changes	4/0
Resistance to bringing new and unfamiliar suppliers on-line	4/0
Strong company culture that preserves the status quo	4/0
Inadequate communication of benefits to appropriate organizational units	2/0
Individual career concerns: developing new and wasting old knowledge	1/0
Narrow focus of adoption decisions ("cherry-picking", "quick fix")	1/0
Resistance by union	1/0
Shifting emphasis on different adoption targets ("material of the month")	1/0
Total	**72/8**

Composite Specific Issues	Totals/Most Serious Barriers
Total cost	14/3
Concerns about design methods and capability	13/1
Supplier capability	11/0
Concerns about lack of field data	9/2
Raw materials purchase costs	6/1
Total	**53/7**

Processing Issues	Totals/Most Serious Barriers
Manufacturing variability	13/1
Assembly requirements	11/0
Process time	10/1
Costs of tooling for high volume production	10/0
Lack of production experience	9/1
Quality control challenges	8/1
Labor intensity	6/0
Processing costs	4/0
Worker protection	3/0
Environmental discharges	2/0
Total	**76/4**

Technical Issues	Totals/Most Serious Barriers
Recycling	17/1
Adhesive bonding	12/2
Mechanical attachment	10/1
Material attributes: modulus, strength, thermal expansion, etc.	8/2
Heat tolerance	8/0
EMC/RFI compatibility	4/0
VOC release	3/0
Flammability	2/0
Total	**64/6**

Application/use Issues	Totals/Most Serious Barriers
Energy absorption in crash	14/2
Structural integrity in crash—impact protection, low car mass	10/1
Concerns about appearance	10/1
Uncertain liability for early adopters	8/2
Reparability	8/1
Durability	5/0
Concerns about consumers' perceptions of implied "quality"	2/0
NVH performance	2/0
Total	**59/7**

Table 21. Facilitators of the Adoption of Structural Composites

General	Totals/Most Serious Barriers
Clear evidence of cost/benefit of adoption	20/1
Involvement of appropriate key personnel in learning/adoption process	8/0
Permitting sufficient time for learning/adoption processes	8/0
Clear, high level champions	5/0
Sufficient resources	4/0
Individual career rewards for learning/adoption	2/0
Ensuring against negative individual consequences of learning/adoption	1/0
Total	**48/1**

Structural Composite Specific	Totals/Most Serious Barriers
Vehicle objectives for weight reduction	16/1
Vehicle objectives for fuel economy	16/0
Vehicle objectives for cost reduction	15/1
Design attributes	12/0
Low costs for low volume production	12/0
Vehicle objectives for corrosion and rot resistance	7/0
Improved NVH	5/0
Long life	4/0
Formability	3/0
Specific strength	3/0
(Not Asked) Parts consolidation	1/0
Total	**94/2**

Table 22. Effective Industry Steps to Expand the Use of Structural Composites

	Subtotals	Totals
<u>Demonstration Projects</u>		21
Create a materials application center that would work on materials, design, production and develop prototype vehicles.	2	
Make the best business case possible using the best and proven applications to show proven advantages and success stories	2	
Test material in vehicle-type situations rather than in the lab	2	
Make parts, run tests on line pieces for bolt-on applications	2	
Focus on parts that have a high rate of return	1	
Demonstrate successful components	1	
Demonstrate successful parts integration	1	
Develop effective crash absorbing systems using composites	1	
Help develop applications	1	
Molders and material get together to fund dual path programs at OE	1	
Target a segment and show they can compete with metals successfully	1	
Suppliers bring in more hands-on demonstrations of processes and materials	1	
Continued demonstration projects	1	
Institute "take-back" program at the end of vehicle life	1	
Target key applications in vehicle and help develop them	1	
ACC		
Design and build a composite vehicle that can be built at high volume	1	
Create a "business unit" to develop and manufacture a frame	1	
<u>Process Improvement</u>		14
Reduce cycle times	2	
Develop manufacturing discipline to ensure quality	2	
Manufacturability a huge problem by product and application	2	
Manufacturing reliability at low cost	1	
Develop processing and assembly in high volume	1	
Learn process controls	1	
Improve cycle time	1	
Develop more computer-aided manufacturing	1	
Lower die costs	1	
Improve process control	1	
Reduce costs	1	

	Subtotals	Totals
Information Efforts		14
Unify language, verify test methods and procedures, have standardized data and industry—wide standards and unified test methods	3	
Co-operatives that store all the properties of the products on data bases	2	
Build database of information	2	
Up-to-date cost and technical data	1	
Information on long term effects on composites	1	
Readily available design parameters	1	
A decision tree that gives value of a pound saved to a vehicle	1	
Supply base material properties	1	
Supply wear data and POP data to material engineer	1	
Participation in ACC will lead to benchmarking	1	
Recycling		6
Recycling	5	
Give public relations money to 3-4 national labs to develop volume recycling	1	
Improve Modeling/testing		6
Work to eliminate technical unknowns	1	
Develop non-destructive testing methods	1	
Improve ability to model behavior of materials	4	
Product Improvement		6
Lower costs	3	
Produce consistent material	2	
Custom fibers	1	
Supplier-OE Relations		5
Be a full-service supplier	1	
Education and training for us to become comfortable with composites	1	
Devote resources to develop low risk component for first application, with customer	1	
Have a relationship with OEMs that gets product in testable vehicles	1	
Train designers for structural composites so they buildup design experience	1	
Other Strategies		6
Make use of ACC	1	
Work on image of the industry and product, turn perception around	1	
Show detailed success stories	1	
Admit currently where you are and why	1	
Go after business that makes sense	1	
Target less difficult problems	1	
Total		**79**