On Lightening Aircraft

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Introduction and Summary

This loosely connected set of musings evolved from an internal image of Herman Miller's popular Aeron™ mesh-seat executive office chair as both a practical example and a metaphor of how transportation could be effectively lightened, and thereby made significantly faster, more efficient, and notably more comfortable. The entire current Aeron execution is not particularly light, because its wheeled movement must cope with a potentially high center of gravity, balancing and compensating for the weight of its sitter. But if its seat frame instead became part of a larger structure, the inherently greater comfort and potentially much lighter weight of its key component, the mesh body support, could be even more effectively harnessed. Its partial transparency would provide not only reduced dead mass but also a vital visual sense of freedom. This thought pattern leads, in turn, to many other aspects of reduced weight design, with a host of benefits, not least increased efficiency and reduced operating costs.

Traditional engineers may most readily appreciate extrapolations from the Aeron to new places for composite materials (including an expansion of their definition), along with a more complete integration of smaller structures into active physical concert with the whole. A broader design leap creates possibilities by enlarging the concept of flexibility. Interwoven into the discussion are negative as well as positive examples, since the former are vital to consider for engineering and public understanding of why some issues are raised, and as a basis for examining what might be done to improve the resulting problems.

The immediate frank and explicit goal of this essay was to illustrate how I could provide ideas, both general and particular, as a part of design team, ideas which would amply repay my inclusion as a professional in that team. Along that way, I have taken stylistic risks, including a possible lack of a sense of engineering *gravitas* through the injection of occasional humor, along with an avoidance of mathematical symbols or much use of other jargon. Then, seeming tangents and unusual language from my diverse personal and professional experience point out valuable possibilities, which could otherwise be overlooked.

A more serious risk of this presentation, beyond not being invited to join a development team, would be use without remuneration of the creative concepts presented herein. They include true innovations, so rather than just brief statements, enough detail must be given to demonstrate how they should work. My experience in analogous situations has not been encouraging, having seen millions of dollars come directly from my musings, but none shared back to those ideas' originator. Nevertheless, the hope of actively working with others on a major design project, with both financial and intellectual feedback for ideas, prompts me to submit this to you.

These ideas herein are inherently not linear, but, as J.R.R. Tolkien wrote, "not all those who wander are lost". What may seem initially tangential should grow into meaningful connections. The piece should also be profitably browsable; I encourage skimming forward if your eyes begin to glaze. For a more strictly engineering discussion of new suggestions, skip immediately to page 3.

There are nuggets ahead, which should be developed into gold.

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General Principles

Heavy vs. Light

Lightness, materials, and efficiency

Of should-be importance to transport engineers' hearts is the principle that the lighter the machine, the more efficient and the faster it can be, allowing at the same time less impact at many levels. Despite commendably intensive efforts in aircraft design, overlooked possibilities inherent in my central practical example, the Aeron chair, underline how there are a great many magic materials out there, which have yet to be thoughtfully deployed in transportation (remembering Isaac Asimov, who equated magic with technologies not yet fully understood by their viewers).

Perceptions of lightness

Problems in the public's perception of lightness center around associations for it with fragility and lack of durability. These stem in large part from the too-common corporate equation of "light equals cheap", and having left their customers without valid alternatives. In counterpoint, any racing mechanic, driver, rider, or pilot in a sport without weight restrictions can quickly testify about the positives of reducing mass. Lighter means lessened stresses, greater potential for performance, more control capability, and less energy carried into impacts if they do happen. Thoughtful students of materials and developments of racing technology whether in air, water, or on the ground have no problem with either the safety or durability of carefully engineered weight reductions. However, racers' sponsors realize that doing losing weight in the right ways is anything but inexpensive. Reducing weight successfully does require more thought, because it is seldom the easiest way to get a job done, despite the greater level of improvement possible once it is completed. Because there is activation energy involved, it too rarely is done, and then there is even more inertia to overcome, because problems have been "solved" in the heavy old way, again.

Linguistics: light vs. heavy

"Airy" can be a negative term while, paralleling how it was used as hippie slang, "heavy" has its positives. The long-term stability of stone in architecture is among them. But in transportation? "Heavy cars hug the road" was a common expression in the 1950s, but one that failed to consider that, despite its convenience in dampening the effect of potholes and providing some protection in crashes, heaviness intrinsically increased the likelihood and intensity of both potholes and "accidents".

The problem has reappeared, even more massively, with SUVs. Heavy is an example of how English is not a precise language, especially for words in most common use. We are always bending the edges of meaning, sometimes for effect, but often through misunderstanding and oversimplification. The common classification: "light" trucks, are all grotesquely heavy in fact. That group is simply lighter than even less roadworthy vehicles, the kind (semis) that mostly carry stuff that ought to be moved by rail, if at all. Scientific language is not immune, either. The apparent precision of mathematics often also misses underlying conceptual errors and exclusions. The results of misuse of either math or language have created pervasive convictions that unnecessarily restrict positive thinking.

Negative perceptions of "light"

I am not immune, having caught myself using the sound of the word "light" in a negative way this morning when my favorite radio sources were all playing what would generally be categorized as "lite". The variant in spelling is appropriate, reflecting as it does the denaturation associated with that use of the phoneme. For beer as the classic example, watered-down products may sit somewhat more lightly on the stomach but, at least as commonly executed, provide gutless taste and body, despite original goals that were laudable and relevant for an increasingly obese population.

From a past stint as a food engineer, and a fan of denser beers, I'm not sure that *all* things can be effectively lightened, with this point important in conceptualizing lightness for public and personal use. However, most of the things that cannot be lightened or otherwise reduced are also those that tend to need to be used less per unit time, since more makes one fat or otherwise overloaded, or are those that do not need to be moved .

Lightness and elegance

On the other hand, many regularly overlook how often the juxtaposition of lightness does reach into the best parts of our consciousness, whenever "light" is properly divorced from "cheap". Consider Limoges or other truly fine (bone) china, so thin it is translucent, yet surprisingly sturdy. Likewise, crystal stemware, despite its lead content. The very word gossamer. For women, the little black dress. The tapering thinness of fur, whose complex construction produces warm lightness which has never been matched artificially. Even for stone buildings, the glory of Gothic cathedrals is very directly tied to their focus on relative lightness. Less can indeed be more, lastingly.

Lightness and comfort

In further contrast to commonly negative convictions, thoughtfully more efficient, lighter design and lifestyle choices *always* add to overall comfort, not detract from it. Waste, and that weight that creates it, inevitably come back to haunt, whether directly in the form of health impacts (from increased pollution) or noise (which is absolutely tied to weight), or indirectly from cost and harder to accomplish tasks, including speed in travel. Home insulation, for a basic example, saves fuel and raises comfort potential, but the lighter it is, the easier it is to work with, transport, and support.

Personal comfort from doing it lighter

A preference for efficiency and quiet has led to my own investments in laptop computers and lightweight chairs and tables. These make it possible for me to be writing these particular lines out on my deck, gently lit by the shaded sun, listening to the stream that runs through our property, instead of huddling, like too many professionals, in an office lit artificially and noisy from wasteful design.

Minimum weight restrictions

Overlooking vital advantages of lightness to those engaged in mechanized competition has further skewed public perception. This avoidance is tied to industrial thinking that "more is better", which in turn comes from the false premise that profitability is correlates closely with material flows. Not unrelatedly, the competitive edge available through lightening has perversely led to minimum weight restrictions in most forms of racing, invisibly for outside observers. The latest Formula 1 Ferrari weighs just 1,300 pounds, but even that light weight, which routinely travels safely at more than 220 mph, contains more than 150 pounds of rule inflicted *ballast* [*Car and Driver*, March 2004, p. 15]. That additional weight is not needed to protect drivers from crashes whose forces are many, many times more intense than ordinary vehicles face. Paralleling this, the overall transportation weight issue has continued to be made more complex by misleading statistics, especially those that avoid the cause and the creators of intensity in highway accidents, but consider only their victims, thereby making heavier automobiles sometimes appear safer. The propaganda behind the continuing inflation of weight in vehicles available for sale, together with the associated lack of focus on lighter technical developments, lull the public into believing massiveness is both safer and better. Both real progress and widespread general understanding are being frustrated.

More negative examples

Hence, when one starts looking seriously for examples of lightness in practice, it is not too amazing to find how little is being done. Even Frank Lloyd Wright, who championed the idea of expanded possibilities in design, often relied on massive materials like reinforced concrete. He reaped lasting problems as a result. Part of the practical difficulty in public acceptance of lightness is the plethora of negative examples from half done exercises, including many of Wright's own that were beautiful but leaky and rapidly crumbled (despite their mass), along with trains like the original Talgo and many cars, when the lightness needed for efficiency following fuel price increases, but was assumed by short-sighted manufacturers to also be an opportunity for manufacturing shortcuts.

Worldwide costs of weight

These failures have to be seen in the context of a heavily, and often more or less invisibly subsidized competition. This includes drastically underpriced fuel costs to consumers, especially in the U.S., relative to the social and environmental impacts from fuel use. These subsidies create a greatly lessened immediate reward for progress in reducing weight and thereby, fuel consumption. The result is accelerating resource degradation and global climate instability (including generalized warming), along with more immediately apparent unnecessarily early deaths and suffering from higher collision likelihood and intensities. It does not seem to have penetrated the contemporary automotive industry that accident avoidance capabilities from better handling, and other performance benefits, are possible with lighter weight, and would be superior to excess steel. However, this concept should be more quickly understood aloft, where speed has higher limits.

Global impacts

The design of a new class of airplanes is particularly exciting because it could directly address both the problems from excess weight and the myths that create them, not just for flight, but throughout our lives and across the planet. If resource use can be reduced for any function, then more people worldwide could participate in whatever pursuit is being considered. The negative alternative is to imagine a billion Chinese all driving 3 ton SUVs. Perish that thought, as the world would, if such an eventuality were carried out. The positive alternative of using less material to accomplish tasks is that more people could participate and for much longer, with less noise and tumult, giving everyone an increased quality of life. Noise and inefficiency, after all, are directly and inseparably connected, as are inefficiency and weight in motion. Because flight is so difficult, and its expected speeds are so high, the rewards of lightening are especially obvious. If they can be communicated from there to other functions, we could multiply the benefits.

Rigidity

Fear of structural movement

Common among transport and building design constraints has been fear of structural movement. While trees quite notably bend and flex, as do large airplane wings, houses and fuselages have been kept from acting similarly. Why? In the case of houses, the quest for rigidity results in close to an order of magnitude in structural material excess. Joints certainly become a more serious issue in a flexible structure, but if wings can sustain movement, why not the rest? The more one observes what happens to large pieces of nailed wood over time, the less impressed one becomes with the utility (or lastingness) of oversimplified construction. Imagine, instead, a house built with the engineering care of a racing yacht...

Rigidness

Making structures rigid allows certain kinds of design ease. For example, for racing cars it allows wheel geometry to be controlled more simply. However, wherever a rigid system meets one that moves, either for control or responding to external inputs, large stresses concentrate at that attachment point, and must be dealt with. Passing along these stresses through further flexibility, instead of having to absorb them at a single point, can neatly dilute their impacts – if done correctly. Physics, of course, requires that the same amount of force be dispersed, but if that total force is spread out, materials to handle it can be proportionally less strong, and more options are available for absorbing it, or even to utilize it for other purposes.

Rigidity and reliability

One of the magnificent things about commercial aircraft is how much mechanical stress and other abuse they routinely withstand, and for how long, with so few catastrophic failures. Structural solidity is assumed to make this reliability easier, and in some senses it may do so. On the other hand, steam locomotives, the very epitome of massive rigidity, were exceedingly unreliable beasts, while aircraft wings move like trees in the wind, and are exceedingly long lasting, given the stresses they receive. When wings do fail, it is almost always at their most rigid point.

The release point

Structural rigidity in aircraft ties directly back to mechanical linkages between cockpit and control surfaces. For obvious reasons, those links needed to be fairly rigid, since one had to have a consistent response to the pilot's input. Fly-by-wire changed that circumstance in ways that I suspect few engineers have fully considered. Flexibility of movement that is distributed over the whole aircraft does not (necessarily) mean large deflections over short distances. Both wings and trees break if those occur. At critical control points, where impulses have been transmitted from the cockpit through variably flexible conduits and related structures, relative movement could be very small, and essentially wholly restrained at need, just as it is now in trees and wings.

Flexibility

If fuselages flexed like wings

If the pieces are properly integrated from a stress management perspective, including those with such seemingly dissimilar materials as windows, then movement among them becomes a non-issue. All the parts must work together to be most efficient, and when they do, other problems also fade. For example, the whole unit begins to serve as a shock and energy absorber, not just parts of it. If the design has been correct, this reduces net loads on small sections, along with overall deflections resulting from disturbances. In transport, the object can move better with, instead of against, its environment, and so become even more comfortable to ride in. Aircraft do not have to keep wheels in contact with a surface the way a racing car must. What worlds of design would open if airline fuselages were assumed to be capable of flexing like wings now do?

Bird and fish flexibility

Can anyone imagine a bird, fish, or mammal with inflexible (e.g., rigid metal) bone structures? This contrasts with how racing cars have traditionally quested for inflexibility, because of the importance of keeping their wheels consistently oriented to the ground. But neither ships nor airplanes have that need, and even for automobiles there are alternative ways to assure steering geometry. Observations of natural adaptations to air and water teach us much that is useful, with flexibility being very near the top. Just now, watching a soaring redtail hawk near the mountain above my computer screen, the way it shrugged off a powerful turbulence encounter through controlled bendability was most impressive.

Learning from older auto design about useful flexing

Musing on flexibility got me thinking about the "cowl-shake" problem with my aging Alfa Romeo spider veloce. That design's excessive symmetry, many parts that do not contribute to the active structure, and harmonic interaction with road undulations—not simply toplessness or its unusually light weight for a contemporary vehicles—are major reasons why it occurs. The equally open 1930s 8c Alfas, by concentrating their similar total weight in the middle, avoided the problem, even though (and in the current context, perhaps because) they were relatively flexible. Thereby, as reported in a recent *Alfa Owner* magazine, far older machines can be competitive with newer designs if pushed hard. Still newer designs should pay attention to this, since there may well be ways to better harness flexibility, instead of requiring weight-costly and additional stress-creating rigidity.

Harmonics as a danger in flexible material design

Wherever flex enters the system, one has to watch out for harmonics, which are accentuated by symmetry. In an aircraft wing, as with tree branches, tapering reduces harmonically effective symmetry, and fuel adds a water-like dampening effect (albeit requiring internal baffles within the tanks). Neither is used much in cars. Passengers and baggage also offer damping power. However, once one thinks more flexibly, some variants on shock absorbers may be necessary in what might initially be thought of as odd places. On the other hand, the old British lever shock-absorber concept could be varied into in-cable slip limiting friction, and get the job done without weight-adding, single-purpose extra parts.

Other forms of flex

Robert Full at U. Cal. Berkeley has built a robot based on observations of cockroach legs, whose intrinsic springiness allows the creatures to remain astonishingly stabile in the face of outside stresses, without neural input [*New Scientist,* 24 August 2002, p. 24]. This report dovetails neatly with my own realization that perhaps the best existing example of the kind of engineered flexional response may be the downhill ski. Skis respond in a quick and controlled fashion to both torsional and longitudinal stresses from terrain as they move, and to directional inputs from their operator.

Degrees of flexibility

Trees just have to deal with gravity and shedding disturbances, but they do so with fractal dimensions of flexibility, from their whole structure down through the diminishing orders of magnitude in scale that make up that whole. Birds provide a perhaps more directly useful example for aircraft, since they must provide active inputs through their structures as well. Flying animals have a subtle level of flex in their largest and strongest bits (bones and tendons), then increasingly greater amounts in components with diminishing size (skin and muscle), each element having its own specific level of interacting flexibility. There is an amazing degree of finesse throughout feathers, which are complex units that, when hit by a gust, separate automatically just enough to dump excess lift (i.e., beyond what the greater structures can deal with), and then quickly recombine to retain control and transfer muscle energy to keep the animal aloft. But this difficult-to-reproduce complexity may be of more value to ultralights than it is to faster craft.

Adaptability to jets

Large jet engines are quite logy devices, having a slow power spool-up in comparison to piston-based sources. This makes it more difficult to extrapolate an auto racer's vital throttle control to respond to more serious deflections. Nevertheless, one could envision quick bursts from mini-afterburners or separate spacecraft-type thrusters for jets. This could have value beyond passenger comfort, since an ability to deal actively with turbulence stresses could allow for still lighter basic structures, since the aircraft would begin to interact with the strongest external forces instead of simply having to absorb them.

Generalizing responsiveness

As component weight falls, through positive feedback so can engine size and fuel requirements, and with them overall weight. As the overall weight declines, and is more concentrated towards the center, control responsiveness should rise proportionally. From that additional responsiveness, creative additions become possible. For instance, thin booms could be extendable around the periphery of the aircraft in flight, with each carrying sensors that would compare virtual envelope pressures with those on the surface of the plane itself. Borrowing computer analyses from those developed just to keep the "stealth" fighter/bombers in stable flight, control surfaces could then respond to oncoming differences before they make contact, in time to mitigate at least some turbulence effects without using additional power. This could not only further improve passenger comfort, but also potentially increase flight efficiency through the craft working even more directly with, not against, outside forces. Having more of the overall structure become actively controllable could further advance this theme of adaptation through motion rather than conquest through absolute strength. This, in turn, could be simplified by having those structures become more sequentially flexible.

Weight Distribution

In-flight stability

My wife, with whom I often work as an intellectual team, commented that overhead luggage bins not only contributed to the closed in and threatening interior feel inside contemporary jets, but also may reduce flight stability by carrying this considerable weight high in the fuselage. Initially I discounted her idea, arguing that weight carried high assuredly created a problem for cars, where a low center of gravity has all sorts of stability advantages, but these applied only in relationships that interacted directly with the ground. On further thought, however, I began to wonder if sensitivity to turbulence might indeed be reduced if dead weight (e.g., baggage and liquids) was all concentrated low in an aircraft. Logically, lowering the center of mass should reduce the tendency to roll in turbulence. We had observed this design approach quite definitively working on the Norwegian Coastal Steamer, which we took along the edge of the Arctic Ocean in winter through some very rough conditions. Aerobatic ability, after all, is not an expected function of passenger liners, whether on water or in the air, so a fully centered polar moment of inertia is less necessary than it is for a Pitts Special. I have no illusions that the relationship of weight and its distribution to response to turbulence has not been previously explored, but do suspect there is yet more to be profitably learned.

General Comments Re. Design

Openness

Scandinavian principles

The whole area of "Scandinavian design" has many positive examples of lightness, both for absolute mass and perceptually. Perhaps especially familiar are those from Bang and Olufsen, suppliers of shimmering, greatly reduced-bulk electronics, including our own telephone, illustrated above. My wife suggested that B&O's philosophy, like those of racing sailing ships, Colin Chapman's racing cars, and the Sainte Chapelle cathedral's architecture of reduced structure and opened view, is "ask what the essentials are, and look at the function anew."

Pompidou Center

Becoming more particular about alternative possibilities, Kathleen brought up the Pompidou Center, the Paris museum where support structures were first made visible in a public building. Initially, its design was controversial, as it made many people uncomfortable from seeing the workings of a building (or machine). I countered with Robert Pirsig's dictum that part of the world's problems emerge from blind use of machines without a willingness to appreciate how they work, or realize their inherent limitations. An advantage for visible working mechanisms for aircraft ought to be that those most likely to want extreme speed frequently interested in the interplay of form and function, and why things work, and so should be less bothered by exposed structures. At the least, they should be able to appreciate that plush and fast are incompatible. The Pompidou Center has come to be considered a classic and is widely imitated (including the building where I've worked the past few years), even though, of course, detractors remain. A similar positive response for uncovering aircraft mechanisms could reduce both weight and cost of flying machines.

Aesthetic cathedral structures

European medieval architecture may be more familiar to Americans, as progress went from the gloomy, heavy Romaneseque churches to the more airy Gothic alternatives with their glorious flying buttresses, culminating with the seemingly all- glass Sainte Chapelle in Paris. In those cases, far heavier materials than those likely to be found in aircraft were minimized to maximize both functional space and aesthetics, the two being inseparable if done to their highest order. As Isaac Babel said about literature, "Your language becomes clear and strong, not when you can no longer add to a sentence, but when you can no longer take away from it."

Traditional Japanese open structures

One of the most influential books during my student days was centered around photographs of pre-1850s Japanese architecture, which took the post and beam concept further. For their upper classes, it was an explicit cultural ideal that what worked best functionally also emerged as the most beautiful. Nothing was hidden in these admirably lightweight, and therefore low material consumption homes, with the exception of possessions like clothes and spare bedding, which are of the relative order of aircraft baggage. Yet their structural lightness is not to be equated with insubstantialness. Their strength is usefully reflected by their presence in those photographs, which required that they must have survived, in good condition, for at least 100 years to even appear at all.

Summary rule for openness

As a basic rule, then, if any part seems ugly enough to have to be hidden, it is not being designed right. Passenger luggage may remain an exception, although for it the same arguments apply. Bluntly put, needfully hidden objects should be seen to parallel the one thing on an airplane that should have to be hidden, i.e., human biological waste. The aircraft's equivalent, jet exhaust, is already being disposed of outside.

Functional Access

Usefulness of access to function

Even my own Alfa Romeo, which was created by a car manufacturer that has been unusually committed to lightness (and, notably, whose economic success has clearly ebbed and flowed with that attention), hides most of its active components, some behind veils of otherwise dysfunctional plastic. It, too, would have benefited from the dictum that only incorrect design of exposed functional materials fails to satisfy aesthetically. Along this vein, the Pompidou's pipes did not achieve their fullest potential because they were not harnessed for their potential structural support value, conceptually going further beyond how their materials or shapes were reconsidered for their aesthetic as well as directly functional possibilities. Wiring, for another example, has been shielded from interaction with other parts because it has been given no multiple functions, and its inherent coppery beauty not properly exploited. I discovered this principle in an old house I was upgrading, after being frustrated by pipes freezing because they had been hidden in the walls. Instead of massively insulating them further, opening their space, exposing, and polishing the copper pipes solved the problem, made further maintenance easier, and enhanced overall appearance at a single stroke. A more widely accepted example of opened function is the popularity of exposed wooden beams in houses and restaurants.

Ventilation tubes

One potential example for aircraft design carries forward the principle of combing problem solving, attention to detail, and visual appeal. Ventilation air supply tubes for passengers seem unlikely to ever have been considered seriously for their structural or aesthetic potential. On contemporary planes, therefore, they are just hidden deadweight. But imagine designing them to be explicitly load bearing, perhaps of polished thin metal, or something translucent or transparent. The latter should increase function further by allowing for straightforward tracking of any dangerous buildups within, for if they are not clean, they certainly should be! The shapes they would need to follow, both for their sweep through the aircraft and in their air-carrying dimension, should become increasingly beautiful as they become increasingly perfectly integrated into active support function.

Visibly integrated support materials

Leaving underlying support structures open to view simplifies both construction and maintenance, in addition to reducing overall weight and cost, when every piece is integrated into load bearing. If needed, particular sections can be hidden by the equivalent of theatrical scrims, or even projections, rather than by adding heavy cover-up material as is now "normal".

Visual Lightness

Uncommon compromises

The less the visual clutter is, and the longer sightlines are, the less cramped and crowded one's surroundings feel. I remember early 707s having color and art that visually led away from its somewhat physically cramped interior. Our home's narrow kitchen felt bigger as soon as we installed black appliances, which fool the eye into seeing depth. Our central spiral staircase, with its thin black metal supporting cage, provides both a feeling of security and spaciousness, in part from actually taking up less space and using less material than standard stairwell approaches, and even more from its overall visual openness. Yet that open support system contributes more significantly to the house strength than heavier, closed alternatives.

Limits on 747 visual space

A parallel to this comes from D.J. Ingalls (1970), who wrote, "Flat ceiling, wide-aisle gave idea of spaciousness" when describing an illustration of a 747 economy-class mockup.

The associated photo is misleading, because this preliminary design study was open at the front, leaving a dominating broad visual space that does not exist in the production aircraft. Extensive personal experience confirms that after spending many hours cramped inside the product, anyone even mildly claustrophobic is unlikely to have "spacious" arise as a leading adjective for a 747's downward looming solid overheads. Interestingly, the Ingalls book (on p. 191) has a cabin photo without some of the overhead plastic (and that I've modified a bit to remove some more), hinting that there is quite a lot of potential open space available, despite a sub-optimal design for that perspective, beyond the "guppy bulge" behind the pilot where there is a short upper deck. Imagine the ceiling as a clean arch instead of this clutter (or that of finished products)…

Integrating windows

The concept of windows as structurally meaningful components provides another example of combining functionality with visual lightness. Windows at first seem particularly difficult to fully incorporate into load bearing, although they already have become defacto parts of the overall stiffness in many aircraft through glue bonding. Composite thinking, where fine networks of stronger materials (in specific dimensions and directions) and multi-layering can be worked together with increasingly transparent matrices should give much stronger results than the simpler products in current use. Larger windows in aircraft would have many benefits from an aesthetic perspective, including bringing forward more of the visually intrinsic joy of flying and reducing the claustrophobic feeling of today's airplane interiors. Comfort could be maintained through the variety of methods now available to control excess inputs of sunlight, ranging from active electronics to auto-adjusting chemicals, the latter familiarly found in eyeglasses.

Housing and Furnishing Design

Housing design inadequacies

Much of what is commonly done in "new" products is simply a reaffirmation of the status quo, in large part because so little effort is put into serious alternatives. Most balloon frame, plywood-based houses take advantage of only a small fraction of the strength available from their materials, and so suffer in all possible senses, as does the design of most furniture and appliances. The automotive and air transport industries have almost constantly striven to emulate material- wasteful household living rooms, instead of becoming something triumphantly better.

Shakers vs. Wright

It has been a difficult search to come up with good alternative design examples, where less weight conquers not just the problems of clutter and massiveness, but also clearly represents sturdiness, reliability, and strength. Some Shaker designs do meet the test, including our own dining room furniture. These better exploit the characteristic strengths of wood, but have rarely reached to the new materials like layered metals with composites. Frank Lloyd Wright, whom I admire greatly, is often thought of in association with lightness in design, but his creations were very earth-oriented, and so often had a heavy form of openness.

Mistaken truisms in aircraft furnishings

More generally, J. Mac McClellan, editor of *Flying* magazine, wrote in September 2000 [p. 78], “It is a truism that what looks and feels good in an airplane is always heavier.” This comment, widely perceived as true, accompanied a photo of overstuffed, unnecessarily heavy seats dominating an unintentionally ironic, bleak yet cluttered, visually uninteresting, and consequently quite claustrophobic Cessna jet interior. No dimension or color suggesting visual leads into the vastly wider space just outside, while the weight visually as well as practically brings one down.

More Specific Design Suggestions

Mesh Seating

The Aeron chair as an example of lightness

The more focused ideas behind this essay began with the Aeron chair, which has an exceptionally comfortable mesh seat attached to a visually sophisticated design, and thus has enjoyed wide acceptance among the executive class. Because its seat portion weighs but a small fraction of competing padded leather models, the Aeron can serve as a useful example of serious lightening, and for revitalizing conceptual thinking about airliners and more. It has never been coincidence that "light" and "airy" fit easily together. Why should they not be more central concepts inside an airplane?

Functional meshes

The principle of equating lightness with increased comfort works with the superior weight and body support characteristics of mesh for seating, which would suspend people, better isolating them from slight aircraft body motions in a more generally flexible design. Adding a stiffer secondary seat back mesh to the basic Aeron design would protect occupants from bumping from behind by children or thoughtless adult knees would. This could become a more active connection to the overall framework, assisting in load bearing. An ultimate integration would have even the seat faces become structurally active, instead of just their frames and any backing. This makes for some very interesting speculation about a mesh design that would be active torsionally and compression-wise for both the occupant and the airliner. Nevertheless, working with the overall goal of having no irrelevant pieces to the overall structure remains a plus for revolutionizing design effectiveness.

Mesh and flexibility

Perhaps the most intriguing unifying factor for the various concepts in this essay is thinking about how feathers, cockroach legs, and trees work in light of the Aeron chair. Its mesh is so comfortable precisely because its flexibility is distributed across the whole, but unevenly, in a controlled fashion, as it interacts with movements and differences in body shape. Meshes integral lightness, the multi-dimensional additive strength of its unwelded weaving, and the motion-limiting friction within it all contribute to its utility as an example of integrative lightening design principles.

Italian mesh support

That the Aeron seat is not a solitary concept can be confirmed by an illustration in Crate and Barrel's summer 2002 mail order catalog. This features Italian-made mesh seats, with a description amusingly labeling them "air table and chair". It is minimally reproduced on the right.

Dirigible furnishings

Like many others who are still fascinated by alternative transportation possibilities, I have long carried an assumption of airships having uniquely light and light-feeling components. Early Zeppelins used wicker, and remembered from childhood images of theirs and later dining seating were similar to the contemporary Italian furnishings pictured just above. In one example (reduced from Archbold 1994), the lounge chairs appear heavier than my memory of them, but there remain elements of the airship designers' greater interest in obvious lightness than seen in contemporary plastic-surfaced aircraft.

Combining Materials

Cable speculations

A somewhat primitive example of the benefits derived from combinations is the strength advantage of cable (or rope) over single wire (or other material) strands having the same overall diameter. A load separation strategy is one of the most basic means to integrating all components into active load carrying. It can also work by bringing the center of materials more fully into play. In most cables, the interaction among the twists gives additional strength, which may be valuable in things like using wiring as a structural aid. However, there are alternative strategies.

Multi-component tubes

While I was hiking recently, and meditating on another of my long-term goals, of building a truly lightweight sleeping cot, I saw how one approach could also benefit racing and aircraft, among other possibilities. This would base overall support on multi-layer composite tubes, which would be machined to fit closely inside one another, and held together by glues just flexible enough to match the differential coefficients of expansion among the dissimilar materials. In one example, the outer (very thin) layer could be a material like stainless steel for penetration and corrosion resistance or aluminum for minimal weight in less stressful situations. The next layer in would be carbon fiber (or something similar), preferably red or another bright color so penetration or other break in the outer shield would become more obvious. The number of layers (and their materials) could vary as needed, with the result becoming like a tree branch, with differing width and strength "rings", which would be seen when cutting perpendicularly through the assembly. Like the living analogs, overall strength and other capabilities should, if done correctly, greatly exceed the sum of the individual layers, or that of any of the individual materials using the same overall thickness as the proposed grouping.

Multi-component joins

Joints are one of the major hurdles for such composites, beyond the basic precision manufacturing and assembly of the requisite thin-walled multiple sliding or fabricated-together tubes. One could follow the pattern used by trees, and interlink the tubes layer by layer where they join as well as along their main pathways. This would provide strengths, and make possible flexibility, not commonly achieved outside natural systems. Micro-capability milling and assembly machines are already increasingly found in computer and similar industries. New ones could be built to accomplish the sophisticated material interactions proposed here, both for corners and the tubes. As with all mechanical developments, the first examples will be far more expensive than those that follow. As the newspaper cartoon "For Better or Worse" recently suggested, good advice comes from having made mistakes ("experience").

Multi-component wiring

This idea is a variation on the multi-strand cable. It does apply particularly well to wiring, which could constitute the innermost part of the ring-structured composite that I briefly described above. This inner insulated, grouped wiring could be either straight or twisted, or a single wire that takes advantage of the exterior layers for its insulation. Especially if the end or corner joins were carefully done, information conducting wires could most effectively add to the overall structural capabilities of a device, instead of being dead weight, as they now are. To some extent, of course, longer distance communication cables do get both strength and signal capability from multi-stranding, and some even have multi-layering on their outsides, but just as a tree gets stronger with more layers, so should structurally valid multiple-ring wiring.

Hollow center multi-component structures

The above concept is by no means limited to wiring within a contiguous cross-section. Hollow centers will often still be of value for cars and camping, several other situations in aircraft, and many other manufacturing possibilities. However, these could similarly change to multiple-material outer layers, similar to those long familiar in the design of tire treads. Pipes for fluids and gasses are not the least of capabilities that could be improved by such an approach.

Dissimilar materials: a household example

The design of a wooden ladder I recently repaired is really quite fascinating and apropos.

The rather thin hardwood is given additional support by a narrow metal rod, which is both bent and supported at the ends and middle. What it does is act as a spring for the sudden force of a person stepping on the tread. It allows for some deflection of the wood, but both limits its extent and assists in reducing the rate of acceleration (and aids in restoration of the normal state). The quite dissimilar materials, wood and metal, work together better than either would alone. Auto makers used to understand this, but only Morgan seems to remember.

Lubricants as important to effective material flexibility

Among the vital factors missing in dead wood, one which keeps it from flexing as safely, is the lubricating ability of water in the living tree. This concept may go further than most engineers realize, despite lubrication's pervasive importance in engines and other moving parts. Water in living plants acts both as a flexion improver and a damper, like the metal rod/spring arrangement used in a wooden ladder, but more effectively because it so thoroughly distributed. The degree of allowable flex in a living tree is far greater than for dead wood (a general category that very much includes lumber). The difference is because water which is primarily there as a nutrient and nutrient carrier allows for modest slippage among the internal fibers, and becomes a shock absorber for them.

Dissimilar materials aided by non-uniform assembly

For cars and airplanes, we could be learning from both of these observations. Dissimilar materials, acting as supporting elements and spring energy absorbers, may work better if they are not welded along the entire length. Instead of hardened glue, then, a continually or variably viscous material may be the answer for the multiple tube structural supports that I suggested above. This principle has strong possibilities for accident resistance, as well as for more daily stresses.

More on lubricants

Where materials are in closer contact, as in cables simulating tree rings, adding lubricant instead of either hardened glue or viscous material could significantly add to potential strength/flexibility, especially over extended periods of time. This lubricant could be the dry variety, like teflon or nylon, as well as more actively slippery stuff that was (and perhaps is still) routinely employed on ships' rigging. Only experiments will tell, and varied functions will require different solutions.

Storage and Seat Functionality

Structurally useful luggage bins

There needs to be a balance between flexibility and stability, of course, for all constructs. Whether over or under seats, there is no engineering reason that storage bins could not lock into place, and then contribute to overall structural rigidity (as well as keeping stupid passengers from opening them in flight and endangering themselves and all around them). Even better, given lighter seats with more room around them, passengers could lift them before sitting and deposit carry-on items, then lock them in closed, structurally integral bins below, not above, their seats.

Active seats

Flexibility issues of a different nature could arise if seats become an active part of overall structure, through their frames sharing load bearing, and thereby not being irrelevant to strength. That would seem to prevent the ready reordering of interior space. However, structural integration is not necessarily associated with permanence. Clever use of latches and other forms of load transfer connections would make this concept more viable. This possibility must be compared to how the structurally noncontributory seating in jets is hardly flexible in any sense (except in passing through sharp knees from the passenger behind).

Moveable seats for faster boarding

Pursuing seating flexibility still further, suppose some seats were fixed to doors rather than floors, so they moved with them, creating an additional exit space as the door opened? This might be more workable than it appears at the first brush. People like myself, who enjoy windows, would also seem most likely not to mind an unusual experience in boarding and disembarking. This would be added to by being given the opportunity to get out first, with the most claustrophobic time in an aircraft generally coming with the boarding and disembarking crushes while it is on the ground. Latching mechanisms for these seats would again establish their structural continuity, while multiple redundant (and highly visible) safety links would offer passenger reassurance.

Broader Aircraft Design Elements

Diversity

Catering to differences

Based on drive-by surveys of numbers of closed window shades in homes, only about 10% of Americans care to look out. One might expect those traveling to be somewhat more likely to care about a useful view, and psychological studies of shopping behavior indicate a significantly enhanced response to the visible presence of windows. Even if such people are a minority, there does exist a sizeable group who have a claustrophobic reaction to having no or only obstructed access to a window. While most people may seem not care one way or the other, and many prefer to be isolated from external reality, some do strongly prefer to have their travel experience enhanced by as much outside visual contact as possible. These differences ought to offer a real opportunity to designers. Although many potential customers may seem satisfied with an airborne auditorium, others will be far more effectively drawn to a “more comfortable adventure” by being able to see it better. Why not openly bring back a sense of the positive in traveling—interest in movement for its own sake—to the air? On the water, cruise ships are doing it with remarkable success.

Passengers are diverse

The current paradigm in aircraft design all but ignores the idea that passengers are a diverse lot, not a uniform commodity. This may not be a true engineering problem per se, but it is one with considerable design potential as well as enhanced passenger satisfaction. In the original 747, this idea did appear in first class with the upstairs lounge, but the bulk of passengers were given nothing more than different upholstery colors. On most contemporary aircraft, an "open auditorium" approach is all that is on offer. There are, of course, many arguments for that approach. But something that is good never precludes something better.

Bidding for views

If basic aircraft interior design does not change, there still ought to be a mechanism to assist those who do care about visuals. A profitable option for the airlines would be a surcharge not for food, but for enhanced views. Too often, window seats are taken by folks who ignore the view, or worse pull their curtains. From personal experience on boats and trains even when special view rooms are provided, but no opportunity is given to bid for the privilege of using them. This may seem a distant issue to engineering design, but its end product needs to be seen as not just a machine, but as a device to allow humans to be more satisfied with their flying experience. Airline profitability could rise with a varied pricing system for preferred spaces, and designers could get a better handle on true passenger preferences.

Seating Arrangements

Is open seating better?

The concept that open-area seating is a plus deserves a serious re-exploration. Certainly, one can argue that a free span overhead and across the aircraft may have a visual advantage. On the other hand, being visually aware of a huge herd around one (and hear all of them, including the inevitable squalling brat) can be a gross negative. Traveling by rail in Europe, I have been consistently impressed by the relative sonic comfort of compartments, as opposed to American-style open seat plans. Fall-off in ridership has followed changing that traditional pattern. Similarly, a modestly complex birdcage structure of lightweight material might well break up the obviousness of crowding, while directly contributing to the internal strength of an aircraft, and thereby lessening the need for exterior material. By using additional variably transparent structural material, divisions could make seat grouping especially flexible, including offering the opportunity for private parties traveling together to feel thankfully separated from other patrons. Being politically incorrect, but practically on target, the same technique could be useful for aircraft carrying noisy revelers, or those with young children.

Increasing seat choices

Various three-dimensional configurations of seat arrangements should be explored similarly, without commitment to the present single flat space. Boeing did this with multiple levels in its first big "clipper". Modern materials, computerized design, and the concept of making every part of an aircraft contribute structurally should allow three dimensionality in seating design to an extent that has been unthinkable even recently. This would also allow additional possibilities for multiple boarding doors, which could greatly alleviate the currently frustrating, and revenue time consuming, bottleneck of loading and unloading.

Flexibility and choice

In balance, more non-uniformity in compartments and space can create either scheduling headaches or opportunities. With flexible or moveable, variably light transmitting glass or other controllably transparent materials, compartments could be altered in character at need. Computer-interfaced reservation systems should allow passengers the ability to choose sections as well as seats, and to better know what one is choosing. Physical configurations could be restructured in response to demand, with any increase in turn-around time more than matched by potential for increased passenger satisfaction all around. Wall projections and shaped LCD screens (which could be structural), as well as almost invisible lightweight scrims, would all be means of providing more apparent diversity. These, plus reflective metal or light fixed art, could greatly lessen any closed-in feeling from partitions.

Overall Configuration

Bubble fuselage, with alternatives

Expanding thought further, one could go conceptually as least as far as a fully transparent bubble for a fuselage exterior. A favorite truism of mine is that almost any window gives far more resolution and information than the best electronic substitutes. Recently reading Richard Bach's 1975 *A Gift of Wings* was an excellent reminder of the positive forms of excitement available from an airplane. First among them are views available only from well above the ground. I do realize that there are striking differences in people's responses to the idea of being aloft, underlining the need for aircraft to have multiple sections. One for those who love being there (and those who just like stimulation), another for those who are terrified of being separated from the ground by air, and a compromise for those who do not care one way or the other. Some additional choices for those who prefer not to look out include an electronic Virtual Reality (already provided in part by in-flight TV/movies) or thoroughly tinted glasses.

Perhaps the optimal initial compromise is to have an outer area reserved for those who care about windows, thereby leaving the useless (to people like me) center for the fearful, those who feel they need electronic stimulation, and the uncaring. Projections could give the inner sections an illusion of space when desired. The screens could lend an additional purpose to internal bracing and/or non-overhead luggage space.

In the End

This is just a beginning.

Sources

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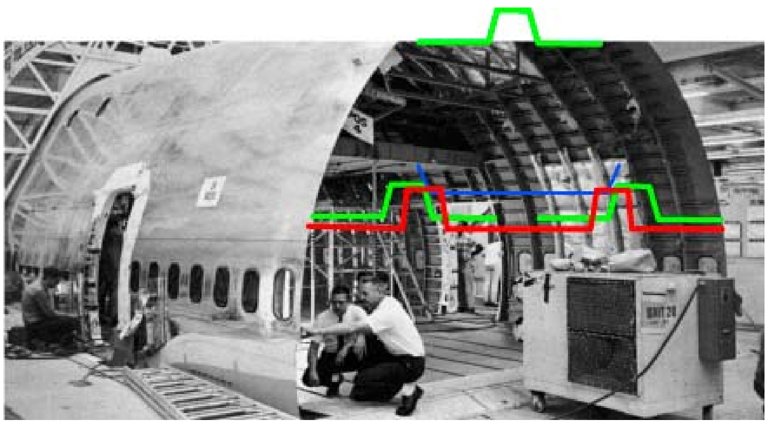
Still More Space

Another Ingalls picture suggests even more waste space overhead. Although a tube shape is desirable for safe and efficient pressurization, why can't more of that space either be opened for the sake of openness, or put some of the seats put up there – instead of being cramped so tightly together? I have roughly sketched a possibility, with the existing useful headroom shown in red from memory of its relationships to the windows, realizing that the temporary floor shown here is higher than in the finished product. There seems to be a lot of empty space to work up there.



It appears as if one might have two lengthwise columns of two seats each, separated by an aisle, along each side of a lower deck. Then add one aisle down the middle of a second deck, with two seats on each side. The ceilings for each are roughly sketched in green, and the second level floor in blue. In the lower center would be room for some of the physical stuff (control paths and air flows) that now inhabits the overhead. There would need to be a second row of windows, with slats over them adjustable for angle from horizontal upward electronically from the upper seats. The upper level would allow the "upper class" to appropriately enter separately and look down on the plebes, who should also have wider, less crowded feeling seats than they now do. The airline would get 12 seats total across, instead of the 11 or less that they now have. The upper ceiling could be arched, if there was not more stuff to hide up there…

Sure, as the picture 747-400.jpg indicates, and when I look carefully at the above, the existing planes do have a second deck, in the guppy bulge behind the pilots, but the alternative has the middle lowered in the main section to accommodate a full length upper. Hell, just who likes sitting in the middle?

Then, how about the railroad thing, that the longer the object, the more aerodynamically efficient?

Paradigm Shift

Looking again at the two images on page 10 brings me back to one of the less easily quantifiable issues: the feeling of control, power, and sheer exultation that comes in larger measure as machines get lighter, when that lightening is done well enough. My elderly

Alfa weighs 2300 pounds, which is to me heavier than it ought to be, yet in comparison to the seriously more ponderous barges that are the only vehicles currently available for sale new, nothing comes remotely close to its feathery, instant responsiveness. No amount of engineering can overcome basic physics. The first problem is that one has to experience this directly to know it fully, to be able to begin to counteract all the lies pounded into us daily by our dominant industries, which destructively pander products on the false basis that the highest profits come from using more and more materials, not more and more creativity.

Yet, the desire for this integral responsiveness, and the more direct involvement it can bring with the worthwhile world around us, in large part fuels the same folks who buy all those unseaworthy highway battleships to supplement them with ATVs and snowmobiles. For the same price as one of those toys, I don't have to tear apart the wilderness to get my thrills, save the ~$50,000 they need for their slow, fuel wasting, awesomely polluting tow vehicles, and drastically reduce my likelihood of killing others on the road (because I can control my vehicle so much more effectively) to boot. Wherever we move in design towards lightness, we go in the same positive direction, and everyone can benefit, at every level.

Where this all comes back together, having just watched two birds playing hundreds of feet above me, is the quantifiable argument that flying can be more efficient in covering territory than movement along the ground – but only when the mover is light enough. Whether we ponderous humans will ever qualify as well as birds do is doubtful, no matter how effective our mechanical support. Then again, some of the lightest airplanes, even with our currently inflexible designs, do outpace all but the lightest (but even more inflexible) ground vehicles in fewer fuel gallons per mile per passenger, especially at any given speed.

Above draft completed 14 February 2004; modest revisions made 29 July 2005 [reBoeingK2illustrated.doc]; reformatted and again modestly revised October 2009