Cabinet Design 101

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Enclosure Design 101 Make it Functional, But Make it Affordable
This presentation is not intended to tell you all there is to know about cabinet/rack/console/enclosure design. We're not going to get into stress analysis, or EMI shielding theory. If we need to, we can arrange other sessions for those things later on.

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What I hope to do today is to give you some general ideas that may help you package your electronic equipment in such a way as to make it functional, affordable, and, just as important, producible. We'll start off talking about some of the things that we need to consider during preliminary planning. Your equipment specification and pure function will drive the big things, so we won't spend too much time on spec-type issues. What I would like to bring to your attention are the seemingly little things that can have a significant impact on the cost and producibility of your enclosures. A little planning up front may save you a lot of trouble, and your company money, later on. I want to pass along some of the practical things that I have seen cause trouble over the years. As simple as some of them may seem these will be the things that cause the most trouble. The big things often overshadow these simple things. But you have heard the old adage that the devil is in the details.

To some of you here, I'm sure some of these issues may be intuitive. But if your mind sometimes works like mine, a little reminder couldn't hurt.

Do you ever give much thought to the stakeholders associated with your designs? When planning our designs, we need to think beyond just pure engineering to consider all of the stake-holders associated with your projects. Who will be affected by how you design the enclosure?

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Who are the stakeholders?

Most importantly, the end user, the warfighter. Most of his concerns will be addressed in the equipment spec. But there are other people involved as well – purchasing, the folks on the assembly floor, Quality Assurance, the installation crew, production management, program management, marketing, and yes, even the enclosure manufacturer. And how about the taxpayer? That hits us all doesn't it. When you are designing an enclosure, your decisions can have an impact on all of these people and their ability to turn your brainchild into a deliverable, serviceable product.

I know you don't feel this way, but I have heard many engineers say that cost is not their concern. Their job is to make the system work. To a degree, that is true. Function is the primary concern of any engineer. But the design that wins the contract is the best design. The one that meets the needs of the most stakeholders at the most affordable cost is the one that gets funded.

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Basic Purpose of Enclosures
No matter what type enclosure, a cabinet, rack, console, or chassis, the basic purpose of these structures is to organize and support the equipment, arrange it in a useable fashion within a limited area, protect it from the environment, and protect the users from hazards. In some cases, it also protects other equipment in the area from radiated signals or heat or noise. This is the functional aspect of enclosure design.

As good engineers, I am confident that you can all come up with ideas to accomplish all of these tasks. You can lay out the equipment so that it's properly spaced, you know the basic physical relationships, like two objects can't occupy the same space at the same time. Even if you miss a few details, your CAD systems will probably tell you if something doesn't fit. But what if you come up with the perfect physical design, but you can't get it built. If it takes some company that builds spacecraft to hold the tolerances, chances are, your budget won't tolerate the costs.

You've found some new material that has all of the perfect characteristics; infinite strength, dissipates heat like refrigeration, infinite EMI shielding characteristics, but it costs $10,000/lb and it has a minimum buy of 10,000 pounds. Your customer is going to be hard pressed to justify the price of your enclosure, and will probably seek alternate sources. Your marketing folks are going to be very upset if the cabinet makes the system unaffordable. Your customer, who has a limited budget, is going to have to decide to buy your system or someone else's. Or they may decide that this system is not affordable so the funding will get transferred to some other program.

That is an extreme example, but what if you decide to use all three-place decimals in dimensioning your enclosure. It may be a basic design, using common materials, but because of the tolerances, it all has to be machined after welding. The complexity of the machining operation could cause the price of the enclosure to skyrocket.

That's what we want to talk about. We'll discuss the basic elements of enclosure design, but I hope through these discussions we'll see some areas where we can meet the warfighters objectives and at the same time do it within a cost structure that lets us keep our projects viable.

And guess what – the government has come up with another acronym just for that concept: CAIV

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Cost as an Independent Variable

How many of you have heard this phrase? In the old days, we had the unspoken luxury of separating ourselves from costs. The name of the game was to have the best hardware in the world so that the Soviet Union stayed scared. If our negotiators could justify the expenditures, the government would pay the price. If it took a little longer than we thought to build a system, just pass the added hours along to Uncle Sam. If we did not get immediate reimbursement, we just increased the bid next time to cover our last actual costs. Defense budgets were great…plenty of money to go around. So cost was dependent on what we decided to build and how we decided to build it. Not the other way around.

Not so anymore. Now we want the best value hardware. All programs compete for funding. If the government has two programs they are evaluating, the one with the most bang for the buck gets the money, not just the one with the most bang. With that thought in mind, we have some control over our own destiny. It is in our own best interest to make sure that we

- Meet the war fighters' objectives
- Set aggressive cost targets
- Continually evaluate our design for improvements in function and cost

What they are saying, in effect, is spend what you need to make things work properly, but don't spend money that doesn't add anything that we don't need. Sounds like common sense to me. Spend the money like you would your own.

So let's get started.

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Plan Ahead

Planning our work is important in any job. With enclosures as with other manufactured items, planning can make or break the job. We need to consider such details as

Quantity
Processes
Materials
Tolerances
Interfaces

All of these things will determine how cost effective it is to produce our design. We'll talk about all of them is some detail.

Producibility. How hard is it to build. This depends on many things. If you have enough money, you can get almost anything made. One of the biggest challenges we face, though, is **quantity.** The fact is, we rarely make enough of anything in this segment of industry to justify a lot of tooling. If you think about the automotive market or the Personal computer market, they have enough quantity to hard-tool everything. They spend millions on tooling. But the per unit tool costs almost disappear. Imagine if you will, though, trying to build an automobile the way we have to build enclosures for Milspec applications. The Rolls Royce would look cheap in comparison. $10,000 won't buy a lot of custom tools, but if you're only building 10 units, that's $1000 per unit.

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Quantity
So the number of cabinets you're going to build should greatly affect how you design it. The quantity will affect how the vendor builds it, what processes he uses, what materials should be used, how it is tooled. Do I make drill fixtures for one cabinet, or do I lay it out by hand or machine the holes in. Maybe there are components that will be hogged out of thick plate instead of cast. Instead of buying a minimum buy of 1000 pounds of a special extrusion for one cabinet, maybe we make some trade-offs and form some special sections out of sheet metal.

If you don't have the quantity to justify hard tooling, think about what processes you can use and what tolerances they will hold, and adjust your design accordingly.

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Processes
What processes will be used to build your enclosure? Do you need it to be welded or bolted together. The equipment spec may define some of the processes, but maybe it will be left to your discretion. Is it sheet metal or structural steel or extrusions or machined hog-out or casting. . Quantity will definitely affect the selection of processes that you use. You don't want to choose a process that requires a lot of tooling if you're only going to build one.

How are you going to get holes into the enclosure? That depends on a lot of things, where the hole is located, is it across or near a weld joint. It might be punched in, drilled in, or machined in. These options are arranged in order of cost. It is definitely cheaper to punch holes in the flat than it is to drill them, and usually drilling in a complex structure is cheaper and easier than machining.

Painting vs. Powder coating
Metalizing vs plating

How complicated is setup?

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Materials

When we select materials for enclosures, there are many factors to consider. The first is availability. Can we get the material in the quantities that we need in a reasonable time?

Not all materials in handbooks are readily available. The more unique the material, the less likely that it will be in stock. This applies primarily to extrusions or special alloys. But some special shapes or alloys are more readily available in locales where they are commonly used i.e aircraft materials are readily available in Seattle, but not necessarily in Baltimore. Shipbuilding materials are available in coastal areas,, but not in Wichita.

In your documentation, if you can, leave a little leeway on material selection. Sometimes a reasonable substitute is available from stock. As an example, we may be able to allow the substitution of sawed plate for steel bars. ASTM A36 for steel plate, ASTM A108 for cold finished steel bar

A568 - Hot rolled and cold rolled steel sheet - general requirements
ASTM A569 - Hot rolled - 0.15% max. carbon - must be ordered pickled and oiled or sandblasted for finishing Replaced by

A1011/A1011M-05 Standard Specification for Steel, Sheet and Strip, Hot-Rolled, Carbon, Structural, High-Strength Low-Alloy and High-Strength Low-Alloy with Improved Formability

We have run into problems with the new ASTM A1008 and A1011 specs due to having to specify strength grades. Sometime a particular grade is not available in less than mill run quantities. Check with your suppliers before locking in a particular grade, or try to provide a range or minimum.

A366 - Cold rolled Commercial Steel, 0.15% max. carbon, obsolete, replaced by:

A1008/A1008M-05 Standard Specification for Steel, Sheet, Cold-Rolled, Carbon, Structural, High-Strength Low-Alloy, High-Strength Low-Alloy with Improved Formability, Solution Hardened, and Bake Hardenable

A659 - Hot rolled Commercial Steel 0.16% -0.25 carbon must be ordered pickled and oiled or sandblasted for finishing
A794 Cold Rolled Commercial Sheet 0.16-0.25% carbon

Some materials are just not available in small quantities. If you design an enclosure that is made from a special extrusion, chances are, there will be a die charge and a minimum buy of several thousand dollars to get it made. That's kind of hard to justify if you are only building one. On the other hand, if you are building a thousand, maybe a special extrusion will eliminate several parts, or several operations.

Hardware Selection
All of the special hardware people are notorious for high prices, minimum buys, and long lead times. Think about that when you are specifying fasteners for the panels or doors. Can you get by with some standard hardware for the prototype and save the exotic stuff for the production run?

Sometimes we can't avoid exotic captive fasteners. I know the Navy does not like loose hardware as a rule, but just be aware that stock fasteners are normally much more cost effective than special order products. Some of the common stocking manufacturers include Penn Engineering & Southco. Although they offer some great hardware, people like Fastener Technology or Innovative Fastener Tech tend to require special orders with minimum buys, high unit prices and long lead times.

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Tolerances

Of all of the details that we get involved with in manufacturing, by far the greatest concern to the people who actually build the cabinet is the tolerances that are put on the drawings. The smaller the tolerance, the higher the cost. Plain and simple. All manufacturing processes have limitations on their accuracy. In the case of sheet metal fabrication, it starts with the sheet metal itself +/- .008-.009 in typical materials, then the sheared blank, then the formed part, then the welded structure, then the painted surfaces. It would be great if we could get exactly what was on the drawing every time, but that is not real world. We can reduce variation in many ways, but because of the quantities that we work with in this business, we have to depend on a lot of hand labor. Exotic hard tooling for low quantities is generally not cost effective.

I've put together a little handout for you that will give some guidance about actual manufacturing tolerances. We can handle most any tolerance, but the cost goes up as the tolerance gets tighter. If you don't take anything else away from this session, I hope that this issue will get you to thinking. When you put a three place decimal on a drawing, please make sure that you really have to have it.

When possible, plan in some adjustments – oversized holes, slots, notches, adjustable eccentric shock pins, shims.

Use functional datum lines or points. I know the CAD system likes to keep everything from the bottom left corner, but the hole pattern around a panel really is related to the panel opening. If you are trying to make something fit the opening, what better reference point. If we tool off of the opening, we can simplify the fixtures or punching.

It's also easier to measure. And if it's easier to measure, the inspection time is reduced, not only for our people but yours as well.

Consider material limitations when you are planning your designs. The materials that you choose will have tolerances themselves, and that, in turn, will affect manufacturing process tolerances as well.

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Steel structural shapes are great to make big, strong cabinets out of. But take a look at the tolerances on this page from ASTM A6, which specifies tolerances for structural shapes. As an example, 3 inch C channel (in the spec these are C and MC shapes) is fairly common in some of the consoles that we build. From the spec, you can see that the legs, or flanges on this channel, are allowed to vary +/- 1/8 inch, and that doesn't even count bow and twist in the length of material. I once had a customer using a 3 inch C channel with 1.5 inch flanges as the primary structure with 12 gauge steel skins. The front panel openings were determined by these channels, and he was trying to hold us to +/- 0.020. We ended up having to hand select the raw material, then add a press brake operation to straighten the channel, then machine the legs of the channel. Talk about adding costs. We would have been well ahead of the game to form the channels from 1/4 inch sheet metal.

I think you can see what I mean about preliminary planning.

Now let's get to the functional aspects:

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Form Follows Function
The design spec is going to tell you the special functions that you have to be concerned about. We mentioned earlier the basic functions: to organize and support the equipment, arrange it in a useable fashion within a limited area, protect it from the environment, and protect the users from hazards.

- Safety First
- Design Must Meet Functional Requirements
- Producibility
- Affordable

Lets briefly touch on some of the nuts and bolts things we need to plan for:

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Safety

First and foremost, whatever else we do with the design – Safety First. Much of this is obvious

•We want to avoid sharp edges and corners as much as possible. But we also need to think about where we place knobs and handles, displays, etc.
•We also need to consider where the enclosure is going to be installed. If the cabinet is shipboard, we want to make sure that if there is a door on the cabinet, it does not close on the maintenance personnel's hand during rolling seas; so we should design in a door stay to hold the door open for maintenance. For the same reason, you may want to specify drawer slides with manually operated locks to prevent them from unplanned closing.
•These things cost extra, though. If the enclosure is for a shore installation, we may not need these extra features. Why not save a little money if these extra features don't really add any benefit.
•Hazardous materials - avoid them if at all possible. Even simple cadmium plated hardware is almost impossible to get anymore. And be careful of the paints and adhesives you select.
•Transportability involves more than just moving the finished product. How are you going to move the equipment around your assembly area. Do you need to design a special skid so that the free standing cabinet doesn't fall on your assembly technicians? Is it a small enclosure, but heavy? Maybe you need handles for a two-man lift, or lifting eyes, or forklift provisions. I've known of top-heavy cabinets with forklift channels with no means of keeping it from tilting off

the forks. It helps to have a closed channel, or at least some type of band or strap that fits under the fork to keep it from tilting off.

Access Control

•Access for operation or maintenance is always a consideration in designing cabinets. But sometimes we need to limit access. Is there a safety or security issue that requires limiting access by requiring special tools, or locks?. Are there shock hazards if someone tries to stick a screwdriver or wire through an air vent? I once had a customer that made transformers for power distribution. They had to make sure that no one could stick a wire or coathanger through the door joint and get electrocuted. The design had a labyrinth around the door interface.

•Should you provide an electrical interlock? Is there a shock hazard if someone opens the door with the power still on?

Noise Control

Noise is more than just annoying, it can affect communication, help an enemy to locate the ship, increase fatigue. There are some things that we can do to reduce noise that cost little or nothing if we think about it beforehand.

- **Noise Abatement**
  - Sizing airflow openings to reduce velocity **Rule of thumb**: Exhaust area should be 1 ½ times intake.
  - Locating fans and blowers and exhaust outlets away from operators.
  - We can add sound absorption materials if we have a big problem
    - Sound Coat

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Design Must Meet Functional Requirements

Space constraints
Environmental demands
EMI Shielding
Accessibility
Human Factors

Human Factors
- Viewing Angles
- Seated or Standing Operator
- Access to Controls and Adjustments
- Maintenance Access

- Frequency of Access
  - Doors or Panels
  - Latches or Fasteners
  - Captive or Loose Hardware
  - Slides or Shelves or Fixed Angles

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Space Constraints

- Height, Width, Depth
- Sway Space

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- Internal Space
- Cables
- Airflow
- Cable Bend Radii
- Air Flow

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- **Environmental Demands**
- EMI Shielding
- Accessibility
- Human Factors
- Environmental Demands
- Shock and Vibration
- Temperature
- Humidity
- Chemical, Biological, Radiological
- Salt Spray
- Moisture (Spray Tight, Drip Proof, Water Tight)
- Dust

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- **EMI Shielding**
- Fields

When designing for EMI shielding, it's important to know what frequencies we are working with and what attenuation levels we need to achieve. This information is important for selecting materials for the cabinet. If we are dealing with magnetic fields, the cabinet material must be magnetic. Otherwise, steel or aluminum or stainless will be adequate. As a matter of fact, aluminum usually works better for higher frequencies, and is often less costly if there are a lot of gasketed joints. We don't have to plate or metalize the joints.

Gasketing material, air vent shielding, joint design, latches, fastener spacing – all of these details will have an effect on the attenuation achieved.

- Access

If we didn't need to get into the box, EMI shielding would be a breeze. But we have to be able to get the components into the box, and then we have to get in for maintenance.

When you are considering access, think about how often you have to get in. If you have to have access frequently, you will have to make it user friendly. That usually means some type of quick release, and a softer gasket material that is easily compressed so that it doesn't take a gorilla to operate the latch.

How do other Environmental Concerns Affect Shielding?

- Air Flow
- Moisture Seals

- Accessibility
  Frequency of Access
- Cables
- Maintenance
- Environment

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Accessibility

- Frequency of access
- Cables
- Maintenance
- Environment

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Human Factors
Noise

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Interfaces

How are you going to get everything to fit and mount? Do we have to have slides for maintenance? The need for access will affect these decisions as well. We have talked about tolerances, but now we have to make those parts fit together to complete the system. The environment will shape our thoughts here. Obviously, the more shock and vibration in the environment, the less adjustment we want because that is where things will shake loose. But we do have to live with the constraints of manufacturing.

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Summary

- **Plan Ahead**
    - Safety First
    - Quantity
    - Processes
    - Materials
    - Tolerances
    - Interfaces
- **Make it Functional**
    - **Safety First**
    - **Watch the specs**
    - **Form follows function**
- **Make it Affordable**
    - **Producibility**
    - **Processes**
    - **Tolerances**
    - **Materials**
- **Make it Producible**

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You're not alone

There seems to be a new spirit of cooperation in the market place, and that's a good thing. Everyone seems to understand that the only way we can optimize our budgets is to work together. Take advantage of the corporate knowledge that exists between your customers, your co-workers, and your vendors. You don't have to be an expert at everything. Sometimes there is a risk in asking questions, but I believe that the greater risk is in not asking.