1

GETTING AHEAD

1.1 FINDING YOUR NICHE

At some time early in my career, I learned that I needed a niche. A niche will be defined here as something you have a need for, do quite well, is unique to you, and is something you enjoy doing. When it is done well, it can make you a highly valued contributor during your career. There are many type niches; for example, an artist may be known for a particular type of artwork done especially well such as oils, watercolors, or pen sketches of nature scenes, or maybe portraits. An engineer may specialize in analyzing and designing a certain type of antifriction bearing. It's something they do very well and is desired by others.

I've always enjoyed working on and understanding machinery. As a young man, restoring automobiles and diagnosing why things failed was something I liked to do.

I decided to go to a 2-year technical college and learn a trade of machinery rebuilding, welding, and machining. The Associate in Applied Science degree program I enrolled in was unique in that it also contained considerable mathematics and physics courses and how they could be used to design machines. By the way, if you enjoy physics you will also enjoy engineering since it is a sampling of an engineering curriculum. I decided I wanted to design things, so after graduating, I went on to receive my engineering degree. My only concern on making this choice was that I was a "hands-on" type person. I was concerned that I might spend my career behind a desk doing calculations. Nothing was further from the truth. As an example of doing both analytical and field work, Figure 1.1 shows me early in my career taking vibration measurements in the engine room of a new ship during sea trials. I had performed

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Survival Techniques for the Practicing Engineer, First Edition. Anthony Sofronas.

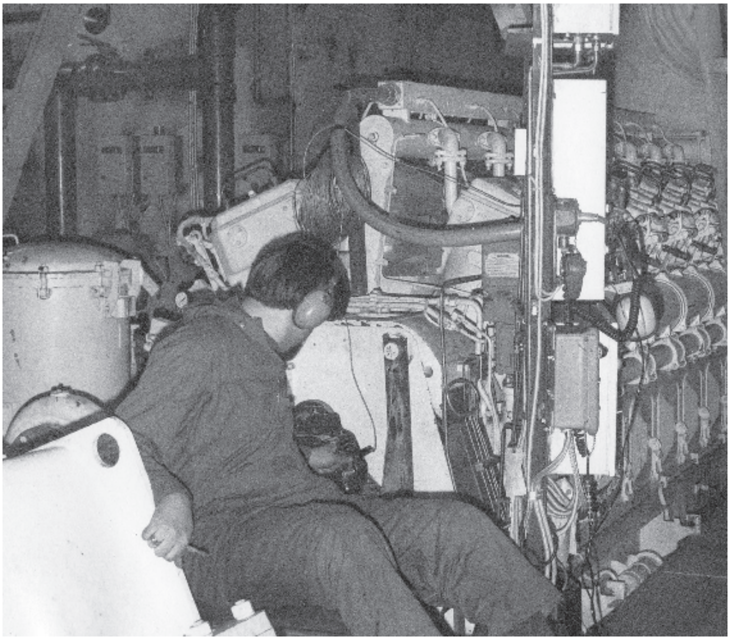


Figure 1.1 Taking torsiograph readings during sea trials.

the torsional analysis of the engine–gearbox–propeller system and designed it to be free of excessive forces and was now verifying that the calculations were correct. This was a lot of responsibility and pressure for a young man. It was exciting, and everything turned out well. Looking at the photograph now, I realize how dangerous it was hanging over a rotating shaft and taking data during the rocking and rolling of sea trials. It would never be allowed these days.

While the majority of my career was designing, evaluating, and troubleshooting machinery, pressure vessels and structures that wasn't my niche. Many people do a fine job in those areas.

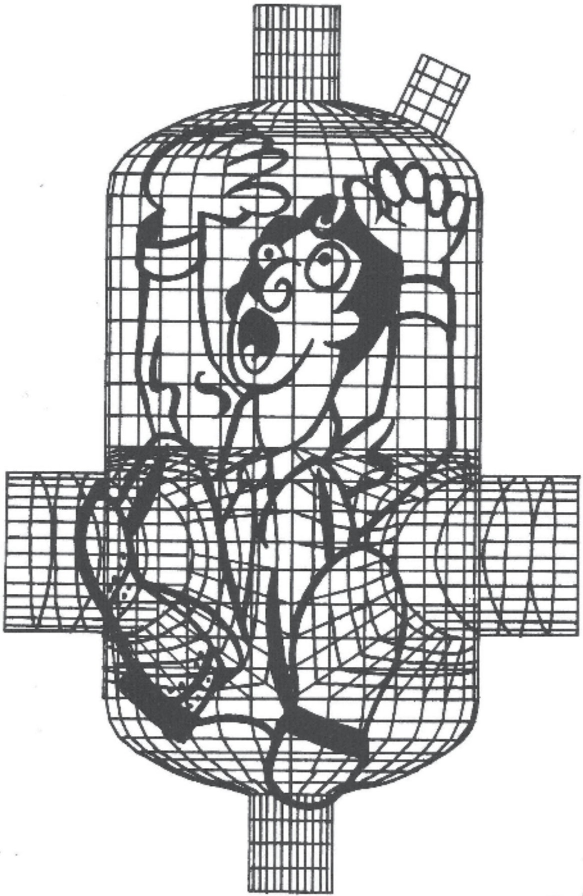
My niche takes a little explaining. As an engineer who enjoys using mathematics to troubleshoot difficult problems, my mathematical skills were not up to the superb abilities of my first industrial mentor. I marveled at the way he solved problems in the most eloquent manner many times using first principles. Now a calculation is said to be from first principles when it starts with established laws of physics and with minimal assumptions or empirical data. For example, my mentor Marty once analyzed the external loads on a complex gear drive system. He started by developing beam-moment equations from the loads and geometry and integrating them to determine displacements. About 20 pages later, he had the solution that was used to upgrade a machine. I still have his report with the beautiful equations neatly and logically presented.

My abilities were nothing of this magnitude, and I felt never to have achieved his mathematical ability. His skills with mathematics were like that of a fine musician making beautiful music. A true virtuoso that couldn't be duplicated.

I mention this because I still needed to and wanted to have this ability, so I developed my niche. I was always good at simplifying tasks. This talent was used to simplify equipment and systems into a form where relatively simple mathematics could be used to solve difficult problems. Sometimes, this also required starting from first principles such as Newton's second law or the energy equations.

In my mind's eye, I would find myself inside the simple model of the machine watching it operate and would model it from there. I might see myself in the equipment hanging onto a pipe as it vibrates or watching a part turn red as it rubs and wears.

Once while explaining this to my son who is a Graphic Designer, I told him that I was having trouble visualizing what was going on inside a vessel I was performing a finite element analysis on. Figure 1.2 was on my desk and that's how he visualized me.



Steve Sofronas

Figure 1.2 Trapped in the finite element model.

The procedure for building a model is fairly straightforward:

1. Visualize, simplify, and sketch the system into the areas that might fail.
2. When there are repetitive elements, reduce them to an equivalent simple system.
3. Make sure the equations include parameters that you can modify.
4. Make sure the failure mode agrees with the data such as a metallurgical analysis.
5. Check the analysis results with other experimental data and be sure it makes sense.

Some of the advantages I've found from being able to simplify systems and build analytical models are as follows:

- A problem can be reduced to a very simple form that is easily explained to others with sketches instead of complex mathematics.
- Modifications can be tested on the model instead of on the actual machine. There is no possibility of a failure if the modification is erroneous. You determine your error on the computer not on the actual system. No one has to know your modification was ineffective and you can easily change it. For example, if you make a reinforcement thicker and the stress is still too high, you change it.
- You can verify your analytical model by using data from other similar failures, tests, or failures found in the literature.
- You can use the analytical model to determine the failure loads and stresses and equipment life. This is like having had a similar failure occur and recording the data.
- You can use all the science and physics you have available as an engineer to develop the model.
- It's extremely exciting to have the actual equipment function like the model anticipated. I found this true with vibration torsional modeling and then having to go do the testing in the field to verify the design modifications I had made.
- As the model developer, you usually have information others are lacking and therefore can provide information to help solve problems.

I've always felt that analytical modeling is the closest I can get to building a time machine. With a good and accurate model built and while sitting at a computer, you can travel back in time to see how a defect could have started to form and then go into the future to see how long it will take to fail. This is truly exciting and amazing especially when it's verified with historical and actual equipment life data. Unfortunately, I haven't figured out how to do this with the stock market. I'm sure someone has, but they are not going to write a book about it and share their secret and neither would I.

Your niche is quite a personal thing. After retiring and writing books and articles on many of the cases I had analyzed I realized not many knew how I had solved the problems. In a working environment when failed equipment is costing your company production losses, all that is required is that you solve the problem. How you solve it is not as important as getting the equipment back in service and explaining what you have done to prevent it from failing again. That's another advantage of a simple model. It allows you to understand what happened, what should be done and to explain this in a straightforward manner to the decision makers.

I'm sure all of you have talents and niches of your own. You should consider developing them further since this is what will help make you unique in engineering.

Sometimes, even if you don't attain the expectations of yourself you were looking for, you find out how to adapt and many times the results are better.

1.2 TWENTY RULES TO REMEMBER

Out of all the work I've published, these 20 rules seem to have gotten the largest positive response from readers and seminar attendees. For that reason, they are stated here again and will be elaborated on in some of the later sections. A colleague provided me with quite a compliment when he commented that they should be framed and hung in every practicing engineer's office.

While rules can't replace common sense or a logical and a methodical approach, they can help avoid embarrassing situations. Here are 20 rules that have been helpful in troubleshooting failures that every engineer or technician will eventually have to do.

The rules have been developed for practicing engineers in the refining industry but should be useful to most engineers and prospective engineers.

Rule 1: Never Assume Anything Making a statement like "The new bearings are in the warehouse and will be there if these fail" is an assumption. They may not be there, may be corroded, may be damaged, or may be the wrong size. The only way you can be sure is to go out and see for yourself.

Rule 2: Follow the Data The shaft failed due to a bending failure, because the bearing failed, because the oil system failed, because the maintenance schedule was extended, is following the data. A string of evidence much in like solving a crime is necessary in problem solving. When trying to solve problems, the person with the data will be the one who can solve the problem. Without data all one has is experience, speculation, or guessing, all which can result in the wrong answer if it doesn't support the data.

Rule 3: Don't Jump to a Cause Most of us want to come up with the most likely cause immediately. It is usually based on our past experience, which might not be valid for this failure. Contain yourself and don't do this and compile data first. This occurs most often when there is a large meeting and everyone is trying to provide input. Be careful when someone of importance or someone who should know does this. Without data, it can short circuit the problem-solving or troubleshooting effort, and focus on only one cause when there may be many interactions.

Rule 4: Calculation Is Better Than Speculation A simple analysis is worth more than someone who tries to base the cause on past experiences. Many an argument in meetings has been solved by going up to the board and performing a simple calculation. It's hard to argue with this type data. Remember engineering is performed using numbers and anything else is just an opinion.

Rule 5: Get Input from Others but Realize They May Be Wrong Most want to be helpful and provide input as to the cause; however, it may not be credible. When interviewing operators, machinists, and others, there are sometimes personal factors that enter into what people say about the cause. This is especially so when one person doesn't get along with another. You need to be aware of these conflicts when collecting data.

Rule 6: When You Have Conclusive Data, Adhere to Your Principles Safety issues are a good example. Your position may not be readily accepted by others because of budget, contract, or time constraints. Before taking a stand, it is important to have other senior technical people agree with you because it could affect your career.

Whenever there are critical decisions to be made, that's the time to be part of a team or form a team to make these type decisions. You don't want yours to be the only name on a document. Engineering decisions are by necessity based on assumptions as all calculations have assumptions built into them.

Rule 7: Management Doesn't Want to Hear Bad News Don't just discuss the failure and the problems it can cause. Present good options that can also be used at other plant locations to avoid similar failures. You will not be popular if you don't have solid methods to correct the problem. You may not need to select which is the preferred option, but you should have the advantages and disadvantages of each. The meeting will be a success if one is chosen or if a next step is outlined.

Rule 8: Management Doesn't Like Wish Lists Only present what is needed not what you would like to have. Adhering to company standards or national codes is usually a wise approach. There are meetings where someone tries to tighten up specifications due to their experiences. The specifications were tighter than recognized national standards or codes and increased the project cost significantly. This didn't go well for the engineer and he was not asked to be part of future projects, which was damaging to his career.

Rule 9: Management Doesn't Like Confusing Data Keep technical jargon to a minimum and present the information as clear as possible with illustrations, photographs, models, and examples. Keep the presentations short and concise. All too often we are proud of the analytical analysis we have done and think everyone else will be too. Most of the time, management just wants the results and what to do next. Details of the analysis are best left to the final report or a trade journal.

Rule 10: Management Doesn't Like Expensive Solutions Only present one or two cost-effective solutions with options, costs, and timing. That is our responsibility as engineers. Present the options best for solving the problems even if the next step is more testing to gather additional data.

Rule 11: Admit When You're Wrong and Obtain Additional Data This is most difficult to do but when other data contradicts yours, it must be done or you will look foolish. In this book, it is mentioned that it is a good idea to have the metallurgical results of a failure available before you present your mathematical analysis. Early in my career I had done this in reverse once, and the failure mode was different than what the Materials Laboratory later determined. The laboratory results were correct and I had to correct my report. It was difficult and embarrassing to do, but it had to be done.

Rule 12: Understand What Results You Are Looking For The analysis was to determine why the rotor cracked, not to redesign the machine. Too often we get so involved in the analysis and forget to just solve the problem. This is especially true for very complex analysis.

Rule 13: Look for the Simplest Explanation First A mechanical engineer might see that a new drive belt was installed too tight and broke the shaft. Computer troubleshooters look to see if the devices are plugged in. Automotive experts make sure there is fuel in the tank. You can then proceed to the next simplest and least costly fix.

Rule 14: Look for Least Costly and Easiest Solution You need to understand what caused the failure first. For example, if a drive belt was too tight, train the machinists the correct tightening procedure. Put a placard on the equipment with the procedure and a caution.

Rule 15: Analytical Results, a Test, or Metallurgical Results Should Agree When the metallurgical analysis says it was a fatigue failure and your analysis says it was a sudden impact, someone is in error. They should both indicate the same failure mode. This was discussed in Rule 11 and shows what can happen if you don't have them agree.

Rule 16: Trust Your Intuition When you feel something is wrong but can't prove it, it's time to do an analysis and get additional data. Your intuition is that little voice in your head that says that this doesn't seem right. All the wiring in your brain store data and observations you have long forgotten, but they are still locked away. So when a shaft looks too small in diameter or a motor looks too small to do the job, you have unlocked a past experience or something you have read.

Rule 17: Utilize Your Trusted Colleagues to Confirm Your Approach Talking with engineering and field colleagues has been the most useful method for finding the true cause of a problem. I usually go out of my way to watch how a job is done or an analysis is performed. After performing an analysis or a design, have someone review the critical ones.

Rule 18: Similar Failures Have Usually Happened Before It is your job to survey your company and the literature for the cause of these type failures and see if it is useful data for troubleshooting this failure. Most pieces of equipment are fairly generic and experience similar type failures. A plant might have several hundred centrifugal pumps. Somewhere in the plant someone has made a repair to prevent a failure. For example, hot alignments on certain type pumps. It pays to be aware of what others have done.

Rule 19: Always Have Others Involved When Analyzing High-Profile Failures When safety, legal, or major production issues are involved, it's unwise to make critical decisions on your own. This is the time for a team approach so that nothing is missed and you have others involved to develop and implement the final solution.

Rule 20: Someone Usually Knows the Failure Cause It has been my experience from interviewing engineers, operators, machinists, and technicians that several usually knew the true cause of a failure. A good interviewing procedure is therefore an important part of troubleshooting. For those that know the solution, give them the credit they deserve.

1.3 CALCULATED RISK VERSUS REWARD

As engineers we like to limit our risks. As a general aviation pilot and mechanical engineer, this has served me well over the years. I didn't do things that were too risky and always had a couple of alternative plans in case something went wrong. For example, when flying cross-country, I always had alternate landing sites in the event that the weather deteriorated. In design, my request for design modifications was always supported with adequate calculations. When someone has done a reasonable analysis, their arguments usually carry more weight than those who are speculating on the cause with no supporting data.

There can be problems with this approach. There is always risk involved in every engineering decision and you cannot progress far in your career if you are unwilling to take some risk.

Consider a large steam turbine vibrating slightly above normal levels with blade fouling thought to be the problem. Management wants to know if it can be run 1 week until a planned outage can be scheduled as thousands of dollars in profit a day are at stake. Your career will not be enhanced if you say it has to be shut down immediately, with no supporting data. Likewise, this is not the time to try your first attempt at online washing of a large steam turbine while it is in operation. This is risky business if you have no experience and no operating guidelines for the procedure. However, this would be a good time to monitor the vibration level, talk with the manufacturer and others with similar machines and then determine the risk in just monitoring the vibration levels. Defining at what vibration level it will have to be shut down will still require some risk, but now others are involved. The reward for doing an online washing yourself and being successful will make you a hero and elevate your status in the company. The risk is wrecking a million dollar machine because of your lack of knowledge. You would never be able to recover from this judgment call in this company and would probably limit your career growth, meaning you would not be trusted with decisions. I don't know about you but to me the reward is not worth the risk. I'd rather be around with the company to solve the next problem.

Obviously, there is much more to this in the judgment-making process, but this illustrates the need for some calculated risk.

1.4 ADVANCEMENT

Salary increases or raises are something we all expect when we do good work. Early in our career, they tend to occur fairly regularly with your supervisor coming to your desk with a slip of paper or it just shows up in your pay check. They are nice and show that your work is noticed and appreciated. The frequency of the raise is built into your department's budget. How much goes to each person in the department, if any, is something the department manager has to figure out. I have had to do this and it is a difficult task that I took very seriously. When someone didn't get a salary increase periodically, it was never a surprise to them because the reason was always in their performance review, which we had gone over. What they had to do to improve was also in the review.

Promotions are different and require much more consideration. When you are promoted, your responsibilities change. A company has a limited number of these positions, and there is usually considerable competition for them. The darker side of corporate politics starts to appear such as favoritism and resentment by others. For higher level promotions, it is sort of like running for a public office and you will need people in your corner.

With these promotions, you should receive a substantial salary increase and other benefits. Along with that will be new responsibilities and the requirement that you develop new talents, more travel, and longer hours with an increased work load. You cannot expect to be promoted and not do more. However, the satisfaction you receive is usually well worth it.

The best way you can understand the requirements of the new position is to look at someone who has that title in your company and realize you would like to do the job better. What would you do, and what are your goals for yourself in that role?

We use to always be amused when a new Vice President (VP) of Engineering was brought into a company. When you are at a prominent position and come into a new area, it seems to be imperative to make yourself immediately known in some way. In this company, the tradition was to paint the offices a different color, say from yellow to pale green. The next VP would paint it from pale green to yellow. It was always fun to watch and occurred several times.

The changes in my titles weren't quite as prestigious but still required that I do something different. One position had me directing a troubleshooting department. The first thing done was to analyze all of the technical and analytical capabilities of the new group and make up a one sheet list on what each of them was expected to be proficient in. This would then be used when visiting our customers at the company sites.

When opportunities were available, the talent in the department was ready to assist the plant. Making sure the individuals went to the correct seminars and also stayed current with the complex software used were also included in the goals for the group.

Once my long-term goal was to be Chief Engineer for a large company. I didn't care for being in management and wanted to stay in the technical arena. This seemed to be the top rung of the technical ladder in the company.

I never got there and after seeing what it required was pleased that I hadn't. I didn't really have the long-term vision for that position nor the communicative skills necessary to work with top management. This position required one to be aware of all activities around the world that were going on in your area. You were responsible for things that went wrong even though it wasn't your fault. You were responsible for the higher level promotions, long-range planning, budgets, equipment improvement programs short- and long-term, personnel issues, and much more. You may have noticed that what is missing are the things I was best at and enjoyed the most, analytical modeling and troubleshooting. The Chief Engineer should assign others to do that type work.

I probably could have gone to a smaller company and been a successful Chief Engineer since I could have performed technical work, but I was quite happy in the company I worked for. There were plenty of opportunities to stay technically challenged. The title, benefits, and prestige would have been wonderful, but the work not as fulfilling.

So with title changes come increased responsibilities and different type work that you may or may not be comfortable with. You will need to make that decision when the time comes.

1.5 LEARN FROM OBSERVING FAILURES

The term failure is not a politically correct term, and lost opportunity, disappointing outcome, or errors in judgment might be more palatable; however, I prefer to use failure. A failure to me means that the outcome of an endeavor wasn't what you intended it to be but represents an opportunity to correct it and do it better.

I once heard and now strongly believe that the only failures in life are those that you have not learned anything from and repeat them. We all have had failures both in our professions and in our personal lives. Some people can be crippled by them and never recover. Others take them as a tough learning experience and tell themselves that they will never let that happen to them again.

Early in my career, I had gone from receiving my doctorate degree in engineering right into becoming Manager of Advanced Engineering. While I didn't know it or was too naive when I accepted the position, this new job eventually required me to reduce the size of the department, meaning letting people go. This was something which I just couldn't do. I left the company after 2 years and went back to doing technical work, which I have never regretted. This could have been considered a failure, but I never did for several reasons. First I learned a lot about myself and what I could and couldn't do and was proud of my decision. I had spent my career developing my technical expertise but was not able to use it in this position. However, I did learn about forming a test laboratory, developing a yearly budget, funding new projects, developing work plans, developing performance reviews, working with high-level customers, and mentoring personnel. This was all extremely useful in my future technical career when I directed a worldwide problem-solving group. So I took something that could have destroyed confidence in myself and used it as a very constructive learning tool. As Winston Churchill once said, "Success is the ability to go from one failure to another with no loss of enthusiasm."

There were not many technical failures since critical decisions were never based on my opinion alone. Input from others on the final design or final modification was always requested. Work was always supported with calculations and historical data and not only with experience. As you will see in later chapters, the ability to develop analytical models to better understand the operation of the equipment was immensely helpful in keeping decisions quantifiable.

Of course, sometimes the analytical models might have been too simplistic or there may have been some important data left out, but there was always the opportunity to learn and improve.

My first job in engineering was working for a company that produced the drive wheels for those big 200-ton off-road vehicles used for mining. They were immense, bigger than some houses and the wheels were huge. I had been working for the company for about 3 years when the engineering manager called me into his office and said he had a job for me. It seems that there was no oil level indicator for each of the drive wheels and the equipment owner wanted them for maintenance. They wanted the driver to be able to see how much fluid was in the transmission before each work shift. The job he said was to design them for field installation on the various vehicles that had already been shipped.

This was not a simple job since there were several type vehicles. Also there were several variations of each and all had different sump arrangements. It took several weeks of reviewing all of the design drawings at the factory and having various welders fit the design to a wheel in the shop. Fellow engineers then came down to see if they could follow the field installation instructions that had been written.

When I felt comfortable with the design, I went into my supervisor's office, put the design and plans on his desk, and told him it was done. To my surprise, he then handed me a plane ticket to an open-pit copper mine somewhere in the western part of the United States and said to go show them how to install it. That was not in my plans.

Explaining to the mine manager why I was there was interesting. He looked over the plans and listened to me with a smile that was disturbing. He then called into the office this 6-ft, 300-pound welder named "Tiny" to install it on Unit 276. When we got to the vehicle, I understood the smile. The vehicle was parked in the normal 4 ft of mud. The top of the level indicator cap would be at 3 ft, meaning 1 ft below the mud. Quite difficult to check the oil level with the arrangement designed. The only thing more embarrassing was the comment received from Tiny. "Do you want me to install it now or would you like to think about it for a while?"

I bring this example up because it shows the importance of actually seeing the equipment you're designing and talking to those who will be using it. You should see the equipment under its worst-operating conditions. Like all embarrassing situations, you realize what you should have done 1 μs after you see what you did wrong. The important thing is to learn from it and not to let it happen again.

You can expect some failures during your career, but they should not all occur early in your career, be consecutive or major.

1.6 KEEP GOOD RECORDS OF WHAT YOU HAVE DONE

Here we will review why it's so important to document failures you have seen.

I'm not a materials person and send most of the metallurgical and nonmetallic work to laboratories for analysis when performing consulting jobs; however, there are preliminary observations engineers can make.

Here are some after the fact analysis meaning there was a good explanation for the cause of the failure. All that is needed for the analysis is a little knowledge and some magnification.

Figure 1.3 represents part of a disk dryer assembly in which two disks were held together with plug welds. A plug weld is a weld from one side only when the other side is inaccessible and in this way leaves a joint with a gap that is susceptible to

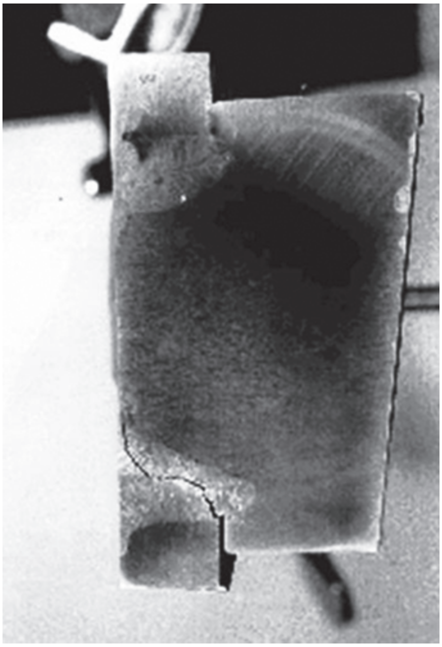


Figure 1.3 Crack growth of a plug weld.

crack growth if excessively stressed. The outline of the weld is evident and has been ground smooth on the left side. The problem with a plug weld is that there is a stress riser where there is no weld material. A fatigue crack can be observed starting from there.

Figure 1.4 is the failure of a titanium connecting rod for a racing car. The fatigue failure is due to a faulty design. Just looking at the failed pieces shows the small piston pin portion had an oil hole in it. It was too thin a design and caused a fatigue crack to grow from the oil hole.

Figure 1.5 represents a large coil spring failure. This was one of several that were failing on a large vibratory conveyor. The failure was near the first small coil where it was bolted to the structure.

It would be quite logical to think this spring might have been overloaded and cracks started on the corroded surface pits. Additional information came from a hardness check of the springs, which indicated this batch of springs had been incorrectly heat treated due to a new supplier being used.

Figure 1.6 is a bolt that has undergone an impacted type bending load. This was one of four bolts in a large mixer that was struck by large chunks of product. The product fell off of the vertical baffles and the blades impacted it much as a baseball hit with a bat.

Figure 1.7 is a stop-drill hole in a stressed plastic piece but could just as easily have been metal. Stop-drill holes are small holes drilled at the end of a growing crack as a temporary repair until a permanent one can be made. The theory is that the drilled hole has a stress riser much less than the radius at the tip of a crack and therefore should halt the growing crack. Figure 1.7 indicates why this is only a temporary repair. At some point, this part was highly stressed again and the hole itself acted as a stress riser causing a secondary crack to start from it.

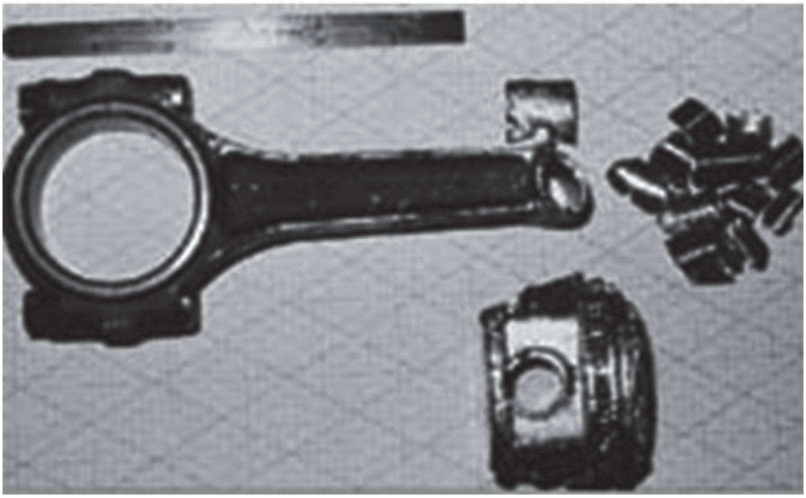


Figure 1.4 Connecting rod fatigue failure.

Figure 1.5 Spring failure.

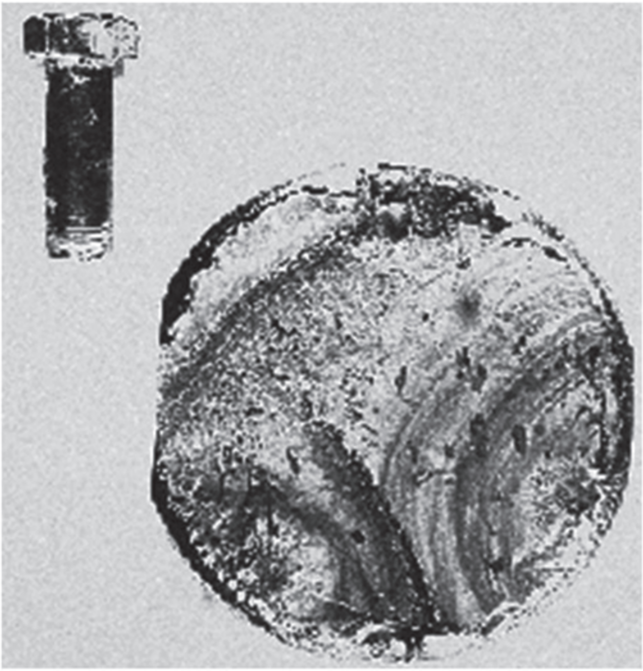


Figure 1.6 Impacted bolt.

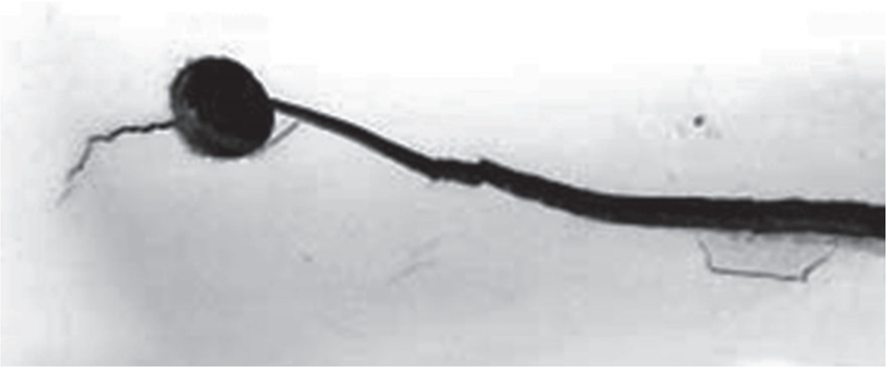


Figure 1.7 Secondary fatigue crack growth.

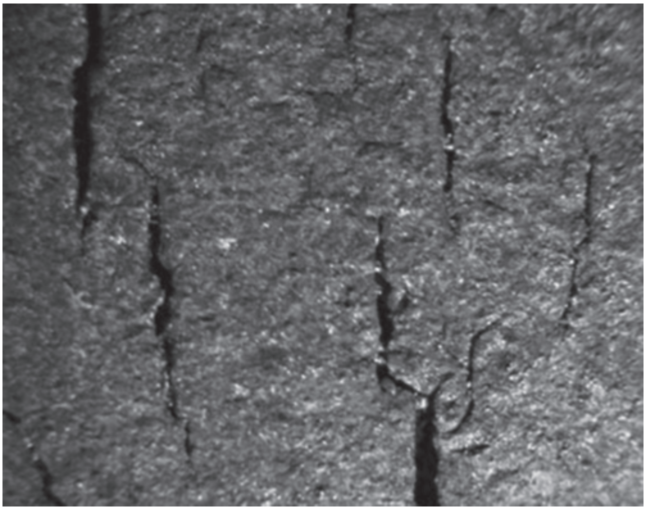


Figure 1.8 Thermal cracking tube ID.

Figure 1.8 represents thermal surface cracking on the inside diameter of a high-temperature furnace tube. The cracks were 1/8 in. deep in a 1/2 in. wall thickness. The outside diameter indicated no cracking. These type failures require a detailed examination by a metallurgical laboratory experienced with high-temperature materials. However, seeing cracks such as this should alert the engineer that this is a deviation from the norm.

The key learning here is to document all the failures you have observed because sooner or later during your career you will most likely see them again. Knowing what the cause was can provide valuable troubleshooting information.

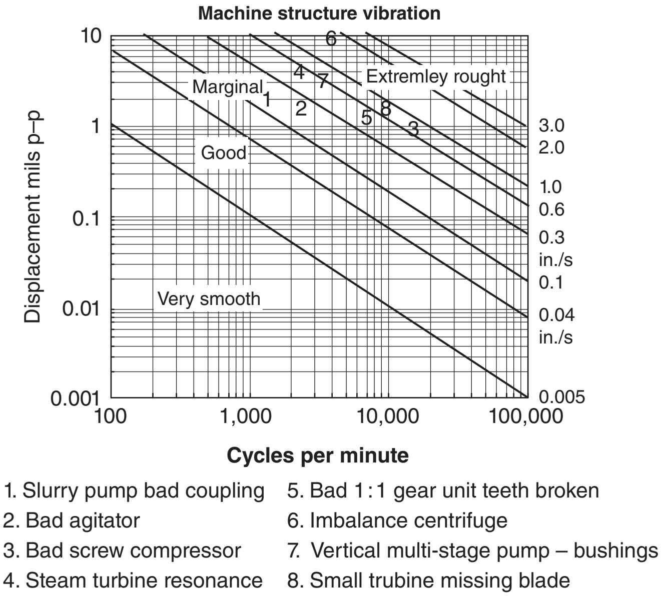


Figure 1.9 Vibration test data [1].

When an analytical calculation is performed or data is obtained, it is recommended to put it in a report, plot the data, or put it in a table of some form. In this way, it will be readily available when a similar failure occurs, which they usually do.

Figure 1.9 illustrates this with some data from vibration testing on equipment. When additional data is obtained, it too can be superimposed on the graph. Note that some details on the cause of the failure are also recorded for future reference.

When you perform an analysis and later find out what the problem was and if you were correct, one approach is to tabulate the data. Table 1.1 illustrates this for bolted joint calculations.

TABLE 1.1 Bolt Loading Calculation History

Application	Bolt Diameter-Length (in.)	Torque (ft-lb)	Relaxation/ Stretch	Preload/ Alternating	History
Vibrating conveyor weight	3/4–10	200	0.002/0.012	14.2	Ok
Agitator paddle	1–3	150	0.001/0.001	1.1	Failed bending, found loose
Agitator paddle	1–3	500	0.001/0.004	4.3	Ok
Cutter blade	3/4–2	275	0.003/0.003	4.9	Bolts loose and broke
Cutter blade	3/4–2	450	0.003/0.005	8.0	Ok
Main bearing cap	5/8–2	5	Loose	0	Failed in fatigue

The table is much larger and as shown is only a sample. From this chart, important bolt calculations and the changes made have been recorded, and it is evident what made them fail and how the modification worked out. This is valuable historical data if a similar failure occurs.

1.7 FLEXIBILITY IN YOUR CAREER

An acquaintance that was a professor of law said that some of the best students he had in his classes had engineering degrees. This wasn't surprising since logical thinking, research, problem solving, and reasoning are some of the things engineers do routinely and most do well. One question to him was why they had chosen to go into the law profession. He said there were many reasons one being that it would be an excellent second degree as it would open even more career opportunities in engineering such as corporate law or as an expert technical witness.

This is not the type of flexibility I mean. The majority of engineers in industry are doing something other than what they received their degree in. Electrical engineers are working as mechanical engineers, computer specialists are process or systems engineers, and as for myself I've worked in multiple areas. One tends to migrate to areas where the job opportunities are. Someone who is an environmental or marine engineer has to know about thermal effects (thermodynamics) and how to design, modify, install, or use instrumentation and computational systems. An engineer developing prosthetics has to understand dynamics, stress analysis, and robotics to name just a few areas.

At one point in my career, I looked at the CEOs of several companies and realized they all started out with engineering degrees. They may never have practiced engineering for more than a few years until their leadership talents were realized, but the strong technical problem-solving and decision-making background was there.

I have worked on a preliminary design for a Martian soil sampler, which was a research laboratory proposal to NASA, locomotive and ship engine designs, aircraft braking systems, racing car frames and engines, refinery equipment design, and manufacturing product testing equipment. I have been troubleshooting various types of machines and structures as well as spending a couple of years as Manager of Advanced Engineering for an automotive products manufacturer, taught at a university and presented seminars on most continents. After retiring, I started my own engineering consulting business not because I had to but because I enjoyed engineering and the people so much that I wanted to continue at it. This just shows the wealth of opportunities and flexibility available with an engineering degree.

1.8 YOU'RE KNOWN FOR YOUR WORK

What you publish distinguishes you from others. A report that is concise and fact filled with new information and a minimum amount of fluff is always welcome. Fluff will be defined here as information that is obvious or readily available and after you read it, you feel as if you have wasted your time. Precis type writing and newspaper headlines have no fluff as every word means something. More about that in Chapter 4.

When someone writes a technical paper and in it states the load is approximately 112.213 pounds force, this is troubling and makes you doubt the person's capabilities. Why has "approximately" been taken to three decimal places? Material properties alone can have variations of ±10% so the decimals have little meaning.

Figure 1.10 is fictitious, but similar ones have been seen in magazine articles and are especially troublesome.

The problem with this graph is that if you calculate the regression coefficient R^2 it is less than 0.2, which means there is no correlation between time and load based on this data. Therefore, the trend-line makes no sense. While in some fields low R^2 occur such as when evaluating people, this is not the case in engineering. So what is the author of this paper trying to do with this graph, certainly not use it to determine a relationship between time and load for this process. The data might be useful without the trend-line if the author is trying to show there is no relationship or the recording instrumentation was in error but unfortunately this is not usually the case.

Here is one more case slightly exaggerated but seen in articles. Figure 1.11 is used to show a "sudden" stress increase over a period of time as determined by strain gauge stress tests.

The problem, of course, is the truncated scale. If the full stress range was shown, a 400 lb/in.^{2} change would hardly be noticed as a bump. It is quite unlikely that any

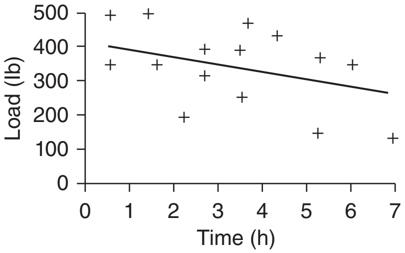


Figure 1.10 Scatter plot of load versus time.

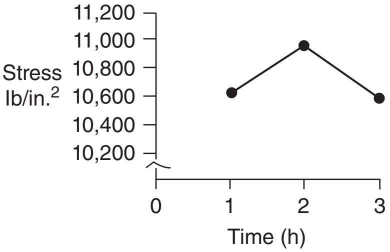


Figure 1.11 Stress–time.

strain gauge testing over this time span could be this accurate. Even if it was, what difference would this small change in stress make?

Many experienced engineers might stop reading the article as soon as data like this appeared and discount the rest of the article. It's important to understand how your readers will interpret your results.

1.9 ETHICAL BEHAVIOR IN ENGINEERING

Each professional society has its own code of ethics that engineers are expected to follow. They are similar and coincide with what most employers also subscribe to. For example:

- Hold safety paramount on any endeavor.
- Be aware of conflict of interests.
- Be aware of confidential and proprietary information.

There will be times in your career when you are aware of safety issues but don't know how to present your concern. This was certainly the case with some engineers [2]. My experience with this is only from reading about past disaster reports that have been published by government agencies.

A basic ethical dilemma occurs to an engineer when there is a possible safety risk that the engineer is aware of or because the engineer's instructions have not been followed. For a consultant, if they do not report this to the authorities, they may have their license revoked. For a practicing engineer, there may be severe consequences to their career especially if there is a major safety concern that eventually causes a loss of life.

Sometimes, going around the internal management of the company to report such deviations is called whistle-blowing. From the reports read, this never went very well for the whistle-blower and it is not recommended unless you are looking for other places of employment.

It's our obligation as engineers to report such safety concerns. Personally, I wouldn't sleep well if I didn't. I would never ask anyone to do something or operate something I wouldn't be willing to do myself.

An approach to solve such a dilemma would be to provide calculations to illustrate what could happen. An example of this is shown in Section 10.10. Here concern was with a safety issue on testing a vessel. This approach was used to discuss how the team could perform the test in a safe manner. It was agreed on and the test was performed without incident. Thus, no so-called whistle-blower situation occurred and the concern was addressed and corrected most amiably.

What would have been done if this didn't convince the project team? Working your way higher up on the management ladder until someone listened was a possibility. What would have been done if no one listened? Document your findings as this would have assigned responsibility to those who would not correct the problem. Most will do something when safety issues are their responsibility. This could have some repercussions as this is a fairly severe step to take. Fortunately, things never usually got to this stage during my career.

Another case was when a colleague Brian reported that in an industry committee meeting he was a member of, someone had reported a safety concern on cyclic pressure vessels used in industry. Since these were high cycle pressure vessels subject to historical catastrophic fatigue failures, he said we should research the subject as it was both a materials and mechanical engineering problem. We decided the best approach to document our findings was to present it to a worldwide forum [3]. After consulting with our company's legal department, we did this with their approval. We had such vessels in our plants that turned out to be nonissues. Others in the industry weren't as lucky. My colleague was to be commended on recognizing the safety issue and wanting to share it worldwide. Our company was to be commended on allowing us to do this.

As professionals it is the duty of engineers to perform our work with the highest standards and integrity utilizing the appropriate tools. We should recognize the value of inputs from our colleagues to insure our work upholds the prestige of our profession.

1.10 HUMOR IN THE WORKPLACE

I've always thought misery would be having to spend time with noninteresting people who had no sense of humor since it would make for a very long workday. Luckily, this never seemed to happen during my career. When I retired, I wrote a book entitled "Family And Friends In The Oil Patch," which was self-published. It told stories of many of the people in my life and their humor. A copy was presented to each person at my retirement party since they were all in the book. I even learned a little illustrating for the book since some of the stories could be better visualized with a cartoon. You see during my career I enjoyed hearing stories people told about their experiences and would write some of them down. Many of these were heard in the machinists break room or with operators in a control room while gathering data for a failure analysis.

An example might be Arlon. Someone at work might ask me what I was waiting for and the answer might be the evening incident report. Asking Arlon what he was waiting for and he'd say, "5 o'clock." I've worked for several companies all over the country and each area has its own specific humor as does each occupation. It was fun to experience them all.

Once I was called by a colleague who resided somewhere in the mid-part of Canada, where it was $-20\,^{\circ}\mathrm{F}$ outside. He was responsible for a gas transmission site. The site had about 20 gas-engine compressors in a long compressor house with doors on each end and compressors on each side of the corridor. It looked something like Figure 1.12.

In the middle of the telephone conversation he said, "Hold on a minute." From the background noise it sounded panicky with many people yelling and alarms going off. When he got back on the line he said, "Sorry about that we just had a moose running around in the compressor house and we had to get him out." Seems like someone

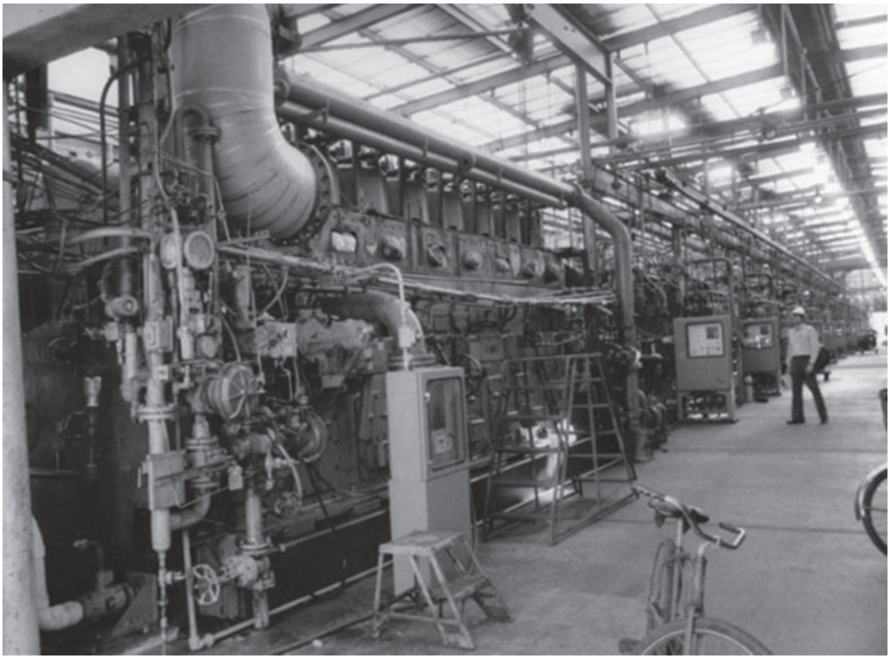


Figure 1.12 Typical compressor house.

had left one of the doors open and the poor old moose just wanted to get warm. You remember things like that.

Some of these stories came in handy when presenting seminars on a subject and they were relevant. They lightened up the presentation since so many of the attendees had witnessed something or someone similar.

We tend to remember people who didn't take themselves too seriously and could laugh a little at themselves and the things they had done. Each of you has had similar experiences and it would be good for you to write them down, least you forget them.

1.11 SELF-PRESERVATION WHEN DOCUMENTING YOUR ANALYSIS

This subject is so important it's in the beginning of this book. It's a caution every engineer who performs failure analysis work should be aware of.

When you are analyzing catastrophic type events such as pressure vessel explosions or machinery impeller containment issues as discussed in Chapter 10, certain precautions are almost mandatory.

First, engineering is not an exact science, and for any analysis, assumptions have to be made. The more assumptions the less exact the results. Even material properties have a statistical range of possible values. Therefore, any analysis you do can always be contested in a court of law by an engineer brought in by the opposing council.

For these reasons, when many assumptions are made in an analysis such as the mode of failure or size of the debris generated, I usually will not publish the analysis with the failure. Only the results of the analytical model are used to justify the suggestions and recommendations made as shown in Chapter 10.

Friends have asked me to analyze modifications made to various engine designs. This is usually done, but the calculations won't be provided to them. After performing the analysis and if the design appears faulty, the conversation with them might be something like, "It appears to be a little weak in the rod pin area and you should have the manufacturer redesign it" or "Make sure you have a detailed periodic inspection procedure in place for the rotor disk so there are no cracks." This would then be discussed with them verbally with some details provided.

You see that as an engineer you may be the only one who has done any analysis on your friend's design. It's just a small part of the design, but you may be thought responsible for more. Even though you didn't evaluate the rest of the design if a safety incident occurs, you may be issued a subpoena and required to be in court as the sole engineer involved. This is also true for the Professional Engineering license. Don't stamp documents that you haven't done the complete design for as you may not know all the details.

When you are doing work for your company, you usually know the people involved and their capabilities. You can go out to the failure scene, interview people, and look at the parts and the metallurgical results. As a consultant, you probably have incomplete or incorrect data so any analysis you do may also be in error. So when the opposing council says "Are you sure you had all the correct data for your analysis?" your answer will have to be "No". And there goes your council's defense and the reason for having you there.

We are usually proud of the work we have done and want to present it. Unless we are using recognized national standards or code calculation software, we need to be aware of the difficulties presented here.

For these reasons, a formal problem-solving method on catastrophic type failures is recommended. Here, there is a team moderator and team members and you contribute to the team and follow a prescribed failure analysis methodology. You are one of several presenting the final recommendations. Here you can show the team your calculations and why you made the recommendations. Now this is a much more self-preserving way to present your analysis and have it implemented with little risk to you.

1.12 DON'T BE OVERWHELMED

When we are asked to solve a difficult problem, it can be overwhelming. Observing a major failure of a complex machine or structure and realizing the magnitude of the problem can be intimidating. Looking into a gear box as large as a truck with all the teeth sheared off or a hole in the side of a compressor with pieces scattered all over the site and the task to determine what happened can appear overwhelming.

That's the way I usually feel before I have any data. In engineering, data is everything and without data we are just guessing.

That's what's so wonderful about engineering; we can obtain the data or generate the data. We obtain it with research, interviews, observations, and collections. We generate data with measurements along with metallurgical and analytical analysis. A hopeless pile of rubble soon becomes a trail of evidence for use in determining the cause or causes.

As long as our approach is organized, logical, and well planned, the foggy nature of a failure slowly begins to clear and the solution becomes evident.

Don't be forced into producing a cause for the failure too early as you will probably be wrong. It's usually better for your career being criticized for taking too long and being correct than arriving at a solution quickly and being wrong. Take time to collect and organize the data as suggested in Chapter 5.

We have all heard the initial national news reports when a catastrophe happens. The knowledgeable people wait until there is some data to report on and those who don't have any idea speculate on the cause. When the true cause or causes are found, those who speculated and were wrong look pretty foolish.

1.13 PROVIDING GUIDANCE TO OTHERS

Most of us will have to provide directions to others on performing a job. The task might be designing something, performing a calculation, or what to do when selected to be on a major project.

Some of us want the person to do the job as we would do it. The problem with this approach is that it might discourage the person from doing it their way. By using their own initiative and not following a "cookbook" approach, a better result may be realized along with the satisfaction of having come up with the solution on their own.

To allow this to happen, I sometimes take the following approach. I will provide general guidelines, such as previous work done or a good book or article along with the necessary cautions. They then proceed as they see most reasonable unless they ask for assistance. I check on their progress periodically and if their approach seems like it will fail I either let them fail, if it will not damage their career or make further suggestions. Failure is a harsh but effective teacher.

Unfortunately, there are those who will not follow suggestions and things may not work out well for them.

For example, an engineering consultant I knew was about to perform a complex three-dimensional finite element analysis on equipment my company was about to purchase. Before starting the analysis, I suggested to the engineer that he should go and see how the equipment operated and do a simple analysis before building the model and contact me if he had concerns. He didn't do this and his model was completely in error since he didn't understand the machines operation. Since he was not working for me, I couldn't periodically review his work nor did I think I had to. His analysis was never used and he lost credibility with me and my company.

1.14 THE TECHNICAL AND MANAGERIAL LADDER TO ADVANCEMENT

It has been said that 70% of engineers consider being managers during their career especially those 40 years or younger. After that age many would just like to be on major projects that interest them [4]. That's why this section is added to the book.

During my career in the three large companies I worked for, there was what was called the technical and managerial ladders of advancement. It was said that one would start as an engineer or technical person and then with enough experience could pursue either. It sounds good but the fact is that some of us are just better suited for one or the other.

I've spent most of my career in the mechanical engineering technical area because that's what I found I do best and enjoy the most. The work/life balance has been just right for me. I was manager of advanced engineering for a few years when I was 40 years old after receiving my doctorate degree. I feel the position was available to me because advanced technical work was being done in the new organization. The Doctor title would indicate to our customers the highly technical nature of the team that would be developing their products. I didn't question the reasoning. Many times we take the managerial route because that's where we think the prestige, promotions, bonuses, and salary increases are. Many companies expect promising engineers to take these opportunities when they are presented to them.

This is an important decision point in one's career and it should be analyzed very carefully as the opportunity for such promotions don't occur often. Only about one in fifteen technical folks becomes manager for most of their career. Once you make the decision to proceed into management, it isn't easy to return to a technical career within the same company. When you have been a manager for many years, you will lose your technical edge as things change quickly in the technical world. Also the bonuses and prestige are hard to leave. During the time I was a technical manager, the finite element method (FEM) and computational fluid dynamics (CFD) which I had used changed considerably. When I went back to the technical ladder from the managerial one, it took me a considerable amount of time to regain that technical edge and yes I did have to change companies.

The term technical manager is used here because that's what most engineers consider, meaning management focused on technical developments. It differentiates from say management of businesses or management of people.

Table 1.2 represents some of the major differences between technical managers and technical engineers that I have experienced.

This table certainly isn't complete but it does include areas I've been most aware of. Some of the areas might overlap but usually they don't. When I say management input is better received by senior management, this isn't because there is a dislike of engineers, it's just that managers have the similar thought processes to each other. For example cost, timing, and probability of success. An engineer would be thinking about how the problem was solved. Studies show [4] that over the age of 50 the notion that high performance results in promotions is less believed. I think the organizations' promotion standards, which can change with time, and high-level positions available

TABLE 1.2 Differences Between Managers and Engineers

Technical Managerial Position	Technical Engineering Position
Potentially higher salary	Can build and develop things
More power and prestige	Make decisions based on own analysis
Higher recognition	Become a well-known expert
Higher level advancement possibilities	Publish your technical work
More perks such as bonuses and travel	See things you have designed
Can make major financial decisions	Can become a consultant
Scope out new products not just a piece. An engineer may work on a piece.	During economic downturns can find other job because of engineering skills
Decisions based on input from others	Can retire, start a business, consult, and present seminars because of skills
Can direct the career growth of others	Salary can be higher than managers for senior level engineers
Directs work through others. Engineers do the work	There is always something new to learn and work on in engineering
Input is better received by senior management	There is more out of the office field work and interaction with the trades

control these promotion opportunities. Having a high-level manager interested in seeing you promoted is also a big plus.

In smaller companies, technical managers may also be doing engineering type analysis and a chief engineer would be an example. In a large company, a chief engineer would probably be doing many of the tasks of a technical manager such as scoping new developments and personal development and would, or should, leave the analysis to the engineering staff. This is what happened to me as a technical manager and it was difficult for me watching the engineers in my group do all of the exciting analysis work. I had technical input but it wasn't as rewarding as doing it myself.

I must admit that the technical manager role certainly had more room for promotions as I saw it done with those in the position before me. My boss who was the director of engineering had my job before me and he wanted to move up to be vice president of engineering. The vice president wanted to retire. The job certainly had the power and prestige with use of the company jet and helicopter, bonuses and possibility of making significant new products, and possibly a new division for the company. All the elements of success were there. It just wasn't a career choice I would enjoy. I had developed my career as an engineer and all of my education and experience were in this area. I felt I could contribute much more as an engineer. Others would have been quite content with that managerial position but you have to be true to yourself. Although I missed the bonuses and company jet, I never regretted my decision.

Engineers need to realize that they should have the experience and develop strong technical skills before they accept a position as a technical manager. They will be more respected by the technical staff knowing their manager understands the technical details discussed. In the short time as manager I had gotten along quite well with my group as I understood the details of what they were doing.

So the question then might be, how does one prepare themselves for a managerial position?

It really depends on the company and its policies, but there are some general areas of importance and many have already been discussed elsewhere in this book.

Learning to communicate well with others is important. Don't make enemies of the wrong people or be known as being annoying or weird. Don't have major technical failures associated with you but be known for making sound and logical decisions. Look around for what you consider successful managers, see how they conduct themselves and try to associate and learn from them. Contemplate what you would do different to be a better manager. Learn to work with and through all types of people and give them credit for what they do.

Joining technical societies, developing and presenting technical papers and being on or better yet heading up committees are ways to develop your technical managerial skills. Making the necessary connections with those in power by letting them know of your presence is always wise.

Having your assignments rotated within the company is a good way to have a better overview needed as a manager. It will also allow you to see and meet other influential people. Staying as the key technical person in a small important area can make you too valuable to promote into management. Actually all of this is valid even if you prefer to stay on the technical side of the ladder as it will make you a better educated contributor.

There can be some luck involved. In my case, the managerial position had just become available, I was available and well known and had done some good work for that organization. I had the title they were looking for and my director knew the organization's vice president and recommended me. I probably wouldn't have taken the job if it wasn't presented to me. I was quite happy with my technical position and saw a successful growth plan. This all changed when I was asked to consider the new managerial position.

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