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METICULOUS ENGINEERING

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Abstract

The need for high reliability and great care in modern engineering is stressed. Disciplines to eliminate or decrease errors are described. College courses should interweave this approach into study projects.

METICULOUS ENGINEERING

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College must cram a lot of basic information into students, teach them to think - creatively, and here I am asking that "meticulous care" disciplines be added.

In college I'd make a real effort to do the work correctly - but then to save time, turn it in for the Professor to check. If something had been overlooked I'd philosophically take the B instead of A. When I started in industry it was a real jolt to find that on much more involved problems my supervisor required that it be right; he did not have time to check it. And now as manager of reliability it is a further shock to realize that the complex equipment for space travel requires greatly increased reliability and accuracy.

A large, complex component of a space vehicle, such as a rocket engine, must have reliability approaching .999. Rocket engine components therefore must have reliability of the order of six 9's. Is this possible? The answer is yes, we have accomplished this. Our rocket engine reliability in space travel this decade is .997, and the weaknesses experienced did not cause a mission failure. We did not achieve this record by asking people, "Please be careful." We follow disciplines to assure that the work was done carefully.

Reliability can be affected by Design, Manufacturing, and Use, and only be these. Everyone else who wants to contribute must do so by influencing these areas. Discussion here will be restricted to the design area.

Certainly new designs will introduce new problems that must be carefully reviewed. But most of the problems will be repetitions of previous experiences that could have been eliminated by extreme care. So strong efforts are made to gather this experience, make it available for use, then to set up disciplines to assure that it is used.

The Experience Retention we are concerned with here is not basic science, but homilies such as "we once did this, with these results", including the influence of "people actions".

Much of the technical society, Air Force, NASA, Technology Utilization, etc., publications are concerned with basic science and its use; although often "experience retention homilies" can be gleaned from them.

The "Case Studies" Dr. Bollay is advocating make an excellent vehicle for such experience retention, as well as for methods of application of scientific information.

In industry much of this is included in reports, check lists, IBM tapes, etc. The use of standard parts (bolts to transistors), and standard procedures (metallurgical to cleaning), is a way to avoid repeating mistakes.

Failure Mode and Effect Analysis is a disciplined way to consider every mode of weakness that can be foreseen, trace it through to its effect on the operation of the component, then the system, and finally its effect upon mission success. All past data on similar hardware performance, collected and used in eliminating previous problems, then stored on IBM tapes, is searched and used to evaluate the chance of such failure modes occurring. Such studies indicate where efforts should be made to eliminate potential failure modes, or to reduce their seriousness if they do occur.

Design Reviews, with specialists from design, stress, materials, quality control, manufacturing, chaired by reliability, thoroughly review drawings and specifications to assure that the design requirements (including interface and environment) are well understood, and that Failure Effect Analysis, trade studies, and past experience have been incorporated into the design. Particular attention is given to the human element in building and using the equipment. We must repeal Murphy's Law which says that if something can be done wrong - it will be. If it is possible to put in a turbine wheel backwards, sometime it will be put in backwards - and not detected till the engine is run. The design must be such that people cannot do it wrong - it must be goof-proof.

It is amazing how many errors can be caught and eliminated in the original design (e.g., an assembly that required a 5 foot wrench to tighten, and no way to hold it). But still more can be and must be done, down to very minor detail. The most recent example of one that was missed was a small screw used in two places, but one passed through a thicker piece so that it did not fully engage the locking device. The component passed laboratory vibration tests, and operated on the engine for hundreds of tests. After three years of use one screw fell out. If this occurred in flight it could easily cause a disastrous short in surrounding electronic circuits.

It would be instructive if students could observe the NASA and Contractor efforts from original concept, through the controls mentioned above, to the final reviews by top management, probing into all areas to assure that proper preventative measures have been taken on all weaknesses that can, or have been found. In a recent review, as an example, it was revealed that a sub-contractor of a valve had gone broke. A top NASA official wanted to know what had been done to see that the new company that would supply this valve hired the key workmen of the old company (in addition, of course, to usual inspections and acceptance tests).

A final point to make is that no engineer can accomplish these results by himself. He uses the experience of many specialists, often working in small teams, in group meetings, and interfaces with management and the customer. Training in working with, and getting the most from other people is necessary to be effective.

College courses and teaching have so changed since my time that I am not qualified to recommend detail improvements. I can just call to your attention this requirement of "meticulous engineering" that perhaps should receive more emphasis in college training, and leave it up to you to work out teaching techniques. For example, the case studies advocated by Dr. Bollay could easily include attention to such detail.

Many schools have a group project that provides the "working with people" atmosphere as well as technical problem solving. Direct special effort to thoroughness in details that otherwise could easily be overlooked. Have the class study how industry does it, then hold a formal design review.

Such efforts are not as glamorous as creative thinking in technical fields, but high reliability of complex systems certainly will be a requirement in future projects. It will be necessary that we heed the admonition: "Do your work like porcupines make love -- very carefully."