HOW TO READ THIS GUIDE

Materials engineers sometimes have problems understanding the philosophy behind the statistical procedures needed when analyzing materials data. This is not surprising. After twenty-five years of teaching statistics at the undergraduate, graduate and professional training levels, I have found that the majority of professionals obtain their statistical training during their undergraduate years, since most do not proceed to graduate school. I also found that the number of undergraduate statistics courses offered at a typical engineering school are three or fewer. Furthermore, these courses are more theoretical than practical in format and content, and they discuss far too many statistical techniques in too short a time. These situations do not help students to mature or obtain a full appreciation of statistical concepts and their applications.

Consequently, statistics is usually one of the most disliked subjects in student life. Instructors are not able to motivate many students and thus cannot teach them the subject matter fully. Since most students never take further formal statistics education, many end up thinking it is an activity where one crunches some numbers into some time-consuming formulas, comparing the results to the numbers in an incomprehensible table, and obtaining some probability values in which they have no faith.

It was only recently that the lack of statistical competency in engineering practice was recognized as a serious problem. Efforts to rectify this situation are already ongoing (see references[1,2,3,4] and suggested readings at the end of the chapter). As students become engineers, they find they need to work with data, perform statistical analyses, and apply their results to real life projects. To their dismay, they discover they lack proper statistical training and now must pursue such training on the job. Many guides and handbooks have been developed[5,6,7] to aid engineers obtain such on-the-job training. While many of these handbooks serve as high-quality reference material for practitioners, their no-frill, practical aspect approach may not be much use to the novice engineer. Such handbooks are replete with statistical formulas, tables, and step-by-step procedures spanning a broad range of statistical topics. The opposite of the problem with college courses, this bombardment of information without any theoretical context may leave the learner confused and intimidated.

Engineers by nature and training are practitioners of applied science, serving as the bridge between the theoretical realm of the scientist and the 'hands-on' realm of the technician. Looking at the problems of college training and on-the-job training in this

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1 **Random Variables, Distributions and Parameters**; Romeu, J.L.; AMPTIAC Newsletter MaterialEASE. Vol. 2, Number 3., 1998.

2 **On Estimation and Testing;** Romeu, J.L.; *AMPTIAC Newsletter* MaterialEASE. Vol. 2, Number 4., 1998.

3 **Application of Statistics to Material Analysis;** Romeu, J.L.; *AMPTIAC Newsletter* MaterialEASE. Vol. 3, Number 1., 1999.

4 **Data Quality and Pedigree;** Romeu, J.L.; *AMPTIAC Newsletter* MaterialEASE. Vol. 3, Number 3., 1999.

5 **A User's Guide to RECIPE: A FORTRAN Program for Determining One Sided Tolerance Limits for Mixed Models with Two Components of Variance**; Version 1.0; Vangel, M. G.; *National Institute of Standards and Technology;* SED. July 1994.

6 **MIL HDBK 5G;** Metallic Material and Elements for Aerospace Vehicle Structures, November, 1994.

7 **MIL HDBK 17 1E**; Composite Material Handbook.

light, it is evident that a gap exists between theory and practice in the continuum of statistical study.

The specific objective of this report is to fill the gap. Many engineers and practitioners who deal with materials data analyses have a strong need to understand statistical methods in order to implement them more efficiently and to interpret their results more accurately. Hence, the overall goal of this report is to provide both the basic understanding and the statistical thinking or philosophy behind the procedures in the materials data analysis handbooks[6,7]. A better understanding of these concepts helps to raise the overall quality of data analysis.

This report originates from the warm response received to a series of statistics articles published in the MaterialEASE insert of the AMPTIAC Newsletter[1,2,3,4]. These articles discussed statistical thinking rather than the practical aspects of the materials handbook procedures. Expanding and building on this experience, this report will provide hands-on opportunities, by going over completely developed practical examples of materials data analyses with full commentary. In addition, the many problem discussions, observations and considerations, combined with data explanations and problem extensions, will provide insight on the application of these methods.

The technical level required for reading this report is introductory, with the assumption that the reader meets two basic prerequisites. First, the reader should have some exposure to introductory statistics, via a general course or direct experience in materials data analysis. Second, the reader should also have some background, by training or practice, in material science.

The body of this report is comprised of eight chapters. Chapter 1 explores the role of statistical analysis in the many aspects of materials engineering as well as product design and manufacture. Not only does Chapter 1 discuss the relationship between statistics and materials data, but also makes the case for *why* statistics does and *should* play such a prominent role in sound engineering practices. Chapters 2 through 5 are based on the four referenced AMPTIAC Newsletter MaterialEASEs[1,2,3,4]. They deal, respectively, with data quality and data pedigree, distributions and parameters, estimation and testing and regression and analysis of variance (ANOVA). These chapters present practical, illustrative examples that enhance the commentaries and explanations.

Chapters 6 and 7 discuss and develop case studies of materials data analyses using methods for regression and ANOVA from MIL HDBKs 5 and 17. These two chapters develop specific expertise in these two areas and constitute the core of this report. The first five chapters intend to bring the reader up to speed in the use of statistics, helping to better understand the latter two. The final chapter summarizes the methods and results presented in this report and discusses possible future directions. A diskette with the analyzed data sets is included for the reader's convenience and practice.

This report does not intend to be another statistics textbook or to compete with other guides or MIL Handbooks 5 and 17. Instead, it intends to complement them, by helping practicing engineers understand and make better use of these excellent reference materials. Statistics textbooks are not targeted for the specialized data analysis in materials engineering work. Hence, the methods required are sparsely distributed among different books and chapters, and are presented at different technical levels in multiple formats. Conversely, the methods in MIL HDBKs 5 and 17 are presented as 'cut-and-

dry' step-by-step procedures, without great explanations or discussions accompanying them.

Some handbook examples will be reworked in a more threaded way (as in case studies). They will also include discussions and extensions, with frequent references made to the handbooks as well as to five selected statistics textbooks[8,9,10,11,12]. The selection of these reference materials rested on two criteria. First, they are excellent, very accessible textbooks and reports. Second, I have ample experience teaching both general and engineering statistics courses with them, and our students have always found them useful and easy to read.

All concepts are introduced through three types of illustrative and practical examples. First, some materials data sets were specifically obtained for this purpose. Some of the simulation examples were created to illustrate specific statistical problems in Chapters 2 through 5. Finally, some examples for Chapters 6 and 7 are taken directly from the references[5,6,7] and are reworked here. In their original source, they were either partially developed or were developed in an alternate manner. They are specifically used here to provide comparisons that yield important insight on the correct use of statistical methods.

The intended audience for this report includes four types of professionals who deal with materials data analysis. The first are data analysts, who need to correctly implement statistical procedures on materials data. The second type are the designers, who need to obtain accurate allowables for their designs. This report will help them to sharpen both their skills and their understanding of how to better use these procedures. The third type are data gatherers, the test engineers and lab technicians who provide the raw material data for statistical analysis. By improving their understanding of the analysis process, they may incorporate that insight into their test procedures; thus helping the analysts do better statistical work. After all, such analyses are only as good or as bad as the data it treats. Finally, engineering managers also have a big stake in this process. Without their understanding and support, the important, costly, and time-consuming activities entailed in generating useful, reliable data would be a waste of time and resources.

The reader will benefit in several ways by reading this report. First, readers will gain a firm understanding of, and an appreciation for statistical analysis of materials data. This is especially useful for data gatherers and managers, who are indirectly, but still affected by this analysis process. Secondly, analysts will better understand the statistical thinking underlying the procedures in MIL HDBKs 5 and 17. This will allow them to place analysis results in a practical context. Finally, all readers will develop better hands-on skills when implementing the statistical procedures in materials data analysis.

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[8] **Introduction to Statistics: Concepts and Applications** (3rd Ed.); Anderson, Sweeney, and Williams; WEST., New York. 1994.

[9] **Mathematical Statistics** (5th Ed.); John E. Freund; Prentice Hall, NJ. 1992.

[10] **Introduction to Probability and Statistics for Engineers and Scientists**; S. M. Ross;. John Wiley, NY. 1987.

[11] **Methods for Statistical Analysis of Reliability and Life Data**; Mann, Schafer, and Singpurwalla; John Wiley, New York. 1974.

[12] **Practical Statistical Tools for the Reliability Engineer;** A. Coppola; Reliability Analysis Center (RAC), Rome, NY. 1999.

Presented below is a comparative table that summarizes all the objectives of this report, comparing them to handbooks and textbooks. These summaries provide context and comparison to other sources. Moreover, one can see how courses and textbooks provide the most complete treatment of statistical theory and formulas. When readers have the time and facilities, this remains their best option. However, books are too general and courses take too long to follow this path if one wants to obtain a working knowledge of the subject in a reasonably short period.

Characteristics And Comparisons Of Various References

Aspect	This Report	Handbook	Textbooks
Theory	Philosophy	Basics	Complete
Formulas	Important ones	Most formulas	All formulas
Examples	Threaded and related	Maze-like examples	Unrelated to field
Computer Work	Specific examples	Some examples	Few examples
Work Focus	Concentrated	Dispersed	General Interests
Specialization	Very specialized	Specialized	No specialization
Independence	Some	Most	Complete
Material Level	Introductory	Specialized	Advanced/General
Reading Sequence	First or Companion	Second	Last
Overall Effect	Understanding	Hands-on work	General Knowledge
Pre-Requisites:	Exposure (one semester) to basic statistics Materials engineering background		
Ideal Sequence for a junior materials engineer or technician:			
1.	Study report material and exercises		
2.	Study Handbook materials and exercises.		
3.	Take a specialized statistics course in college		

Conversely, handbooks rapidly present the basics of specialized theory, providing step-by-step procedures for learning the mechanics of materials analysis work through a maze of examples. While handbooks constitute a great improvement in on-the-job training, they leave out many explanations about the philosophy or use of the statistical concepts they describe, thus disenfranchising the isolated reader. In addition, their extensive material is widely dispersed throughout the handbook, which makes it difficult to follow and read. This report, in contrast, provides a starting point for the beginner who wants to study these topics and a bridge between the more experienced practitioner and the handbooks and texts.

A suggested reading sequence of these materials is as follows: Engineers or technicians with little or no experience in materials data analysis, but with the stated prerequisites, should start by reading the report and working out its examples. Then, as they become acquainted with the methods, they can go on to read the handbook procedures[6,7], using this report as a "study guide". Finally, after acquiring mastery and understanding of these methods, readers could continue on to specialized textbooks and course offerings.

The above roadmap clearly shows the need for a guide that helps the practitioner get through this maze of knowledge and provides the missing explanations and insight to understand them.

It is our sincere hope that this report fills that role.

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Suggested Further Readings

1. **How University-Industry Partnership Ought to Work;** George M. Low; *RPI Alumni Magazine*, Summer 1983

2. **Academe Meets Industry: Charting the Bottom Line**; Elise Hancock; *RPI Alumni Magazine.* August 1983

3. **Providing Effective Training in Industry: An Experience;** T. P. Callahan, H. W. Altland, *ASA 1995 Proceedings on Statistics Education.*

4. **Non-Mathematical Statistics: A New Direction for the Discipline**; Special Section. Undergraduate Education; *The American Statistician;* V. 53, No. 1 (1999).