Preface

There are many textbooks on the subject of feedback control; however, most are highly mathematical and, as a result, often repel the seasoned engineer who may have become a little rusty regarding the rigors of certain aspects of mathematics that include such things as differential equations and complex number theory. In a similar manner, unnecessarily complex mathematics can be a turnoff to engineering students who might otherwise find the control systems engineering field both challenging and exciting.

This book is not a textbook in the traditional sense but an attempt by the author to give back to the next generation of control systems engineers a guidebook containing easy to follow descriptions of the important aspects of classical control supported by examples based on real world events that have occurred during the author's career in the aerospace industry. The arrangement and content of the book is an attempt to provide an effective answer to the question 'What would have been most useful to me as a prospective systems engineer in the pre-to-post graduate timeframe seeking guidance and insight into the fundamentals of feedback control?'.

In the opinion of the author, complex mathematics need not be a significant barrier to learning if a pragmatic presentation methodology can be developed providing a more straightforward approach to the subject that can be more easily absorbed by the practicing engineer and that provides an inspiration to the prospective control engineering graduate.

In the current world of increasing complexity and functional integration in all areas of engineering and technology, the engineer who did not take the course on 'stability and control' operates at a serious

disadvantage. This is a common issue amongst many older mechanical engineering graduates because historically control theory has been a part of the electrical engineering curriculum. Even though this is becoming less typical in most learning institutions the seasoned engineer with a mechanical engineering background has, more often than not, never been exposed to the subject of feedback control theory. An additional problem with academia is the fact that much of the material taught is not in common practice within the industry. As a result the learning experience becomes more of a mathematical exercise that misses out many of the pragmatic methods that have been established as most effective in the design and development departments of industry.

Today's engineers are required more and more to be both specialists in their area of expertise and generalists who understand the complete functional context of the application where their products are being used. Also, many of today's products contain multiple engineering technologies. What once were single discipline mechanical, hydraulic or pneumatic products and systems now contain integrated electronic sensors and, in many instances today, software. Control theory reduces these widely varied technical disciplines into their important dynamic characteristics expressed as transfer functions from which the subtleties of dynamic behavior can be analyzed and understood.

The objective of this introductory book on feedback control is developed around the generic closed loop control system concept illustrated by the diagram of Figure 0.1: As shown, the typical system comprises a

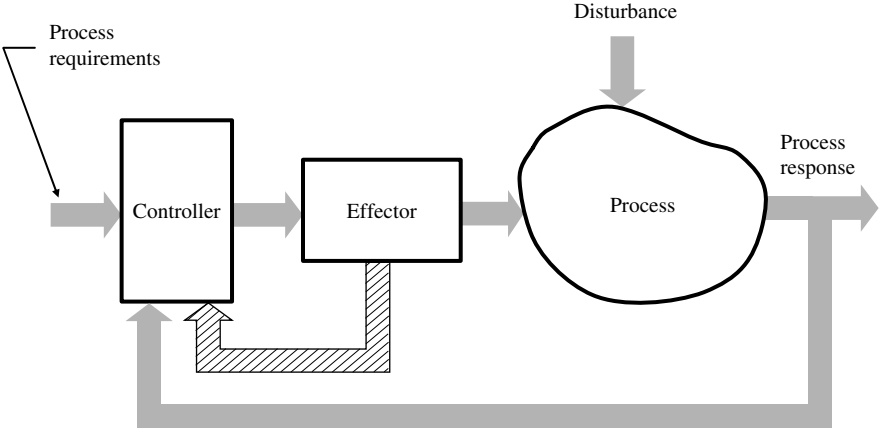

Figure 0.1 Generic feedback control system

control element, an effector and a process to be controlled. The process requirements are compared with the process response in the controller whose task is to generate actions that ultimately bring the process in line with the required state. The effector represents a power amplification stage or 'muscle' that takes the control output signals and converts them into a form that can be used to effect a change in the process. The process may be any number of things from a simple actuator to a major aircraft control system. The arrow connecting the process response to the controller represents the feedback of process states to the controller, hence the term feedback loop. The effector may also incorporate feedback to the controller as indicated by the shaded arrow.

An important feature of the feedback control system is that external disturbances which affect the response of the process will be sensed, and ultimately compensated for, by the ensuing corrective action determined by the controller. The challenge for the control system designer is to establish the best control algorithm that will provide the optimum performance in terms of accuracy, dynamic response and stability. The objective of this book is to provide the reader with the basic tools to understand the design processes and to visualize the functional behavior associated with feedback control systems.

As part of the aerospace series the material presented in this book is related to aircraft control system situations almost exclusively. Furthermore, the extensive background of the author in the areas of flight controls, hydraulics, fuel and engine control systems forms the basis for many of the design examples and reinforcement exercises developed.

At this point it is appropriate for the reader to recognize that aircraft closed loop control systems vary substantially in their criticality and response needs. While the primary focus of this book on stability and control is aimed at the tightly coupled fast response systems where stability and response requirements are important design and operational issues often with demanding specifications, there are many interactive control systems within a typical aircraft that are much more loosely coupled but nevertheless must be recognized and evaluated from a response and performance perspective. Figure 0.2 illustrates this point by showing schematically the functional relationship between the various layers of functionality associated with the control of a modern aircraft.

Shown in Figure 0.2 are a number of nested control loops with control surface actuators at the center which determine the immediate aircraft response and attitude. At the second level is the flight director/autopilot

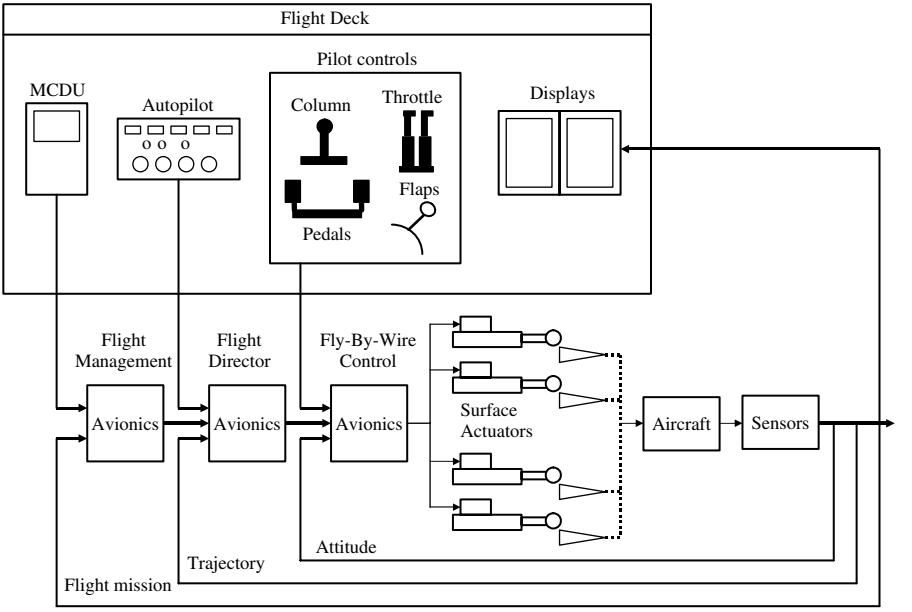

Figure 0.2 Typical integrated flight control system

control loop which determines the trajectory of the aircraft within its local airspace. Around these two control loops is the navigation system which controls the aircraft's mission through space relative to Earth coordinates.

The outer loops become less tightly coupled but they are by definition closed loop control systems and as such must be recognized by the control systems engineer in terms of response needs and potential interaction between the various control layers. These comments are presented here to provide a perspective and awareness to the reader of the complexity of the modern aircraft in terms of stability and control and to be cognizant of the additional 'outer' control loops that are invariably involved in the overall performance of the aircraft.

While the intent of this book is to minimize the mathematical content, all of the key analytical procedures are developed from first principles in the interest of completeness and to satisfy the reader with a strong interest in the mathematics. The underlying methodologies, graphical aids and guidelines described, however, can be developed using fairly simple algebraic principles that are intended to provide the practitioner with a good 'feel for the problem'.

Part of the fascination of understanding the principles of feedback control is learning to be able to appreciate the functional behavior of control systems through the interpretation of simple block diagrams and to appreciate the fact that the dynamic functionality of complex integrated systems is typically not intuitive.

The author has a long-standing belief that a basic understanding of feedback control systems design, analysis and testing allows the design/development engineer to have a clearer understanding of the dynamic functional behavior that results when multiple components are combined within a system to form an integrated functional entity.

The end objective of this book, therefore, is in effect to 'switch on the light' in the dark room of system design and development for those engineers who missed the opportunity to complete formal training in control theory at university. This will provide the know-how necessary to minimize problems with fielded systems in the area of operational performance thus increasing the readers' effectiveness in the eyes of both their employers and their customers.

Roy Langton