The ability to work through a gas turbine engine cycle by hand—at least for the design point—is something that should be acquired by all young engineers. Manipulation of the theoretical thermodynamic process (using simple tables of $C_p$ and $\gamma$ for air and combustion products at various fuel/air ratios) provides valuable insight into flow- and energy-balance, how ideal and real temperatures and pressures are related via efficiency, and the overall iterative approach which must be taken. In fact, such an exercise constitutes the most basic foundation for all performance codes. However, the iterative calculation sequence is quite cumbersome and very time-consuming—even more so when we move to off-design examples and complex engine cycles. So once the basic knowledge has been established, the next logical step, soon taken by most propulsion engineering students, is to capture those same, simple calculations in a spreadsheet. Fortunately, if we are serious about doing this, a number of quite sophisticated computer programs are now available and their use enables us to progress rapidly towards understanding the influence of the relevant design parameters & variables on engine performance without having to focus on specific theoretical details. It is critical that a gas turbine designer or performance specialist does more than enter input data and believe the output! Fortunately, current commercial design codes give us answers within fractions of seconds and enable us to explore appropriate design spaces and the consequences of design decisions in acceptable time frames.

Before running any computer program, an aspiring designer or performance analyst should first think What do I want to accomplish? For example, if the surge margin of the core compressor is marginal, the question is What is the reason for it and what can be done to improve the situation? If a growth variant of an engine is of interest, then what design options are open? If measurements on a test bed indicate a degraded engine performance, which compressor or turbine is the most likely source? Just playing with the input data and hoping that the solution will somehow manifest itself is usually in vain. The well-known phrase garbage in—garbage out should now spring to mind! You should have an idea about what will
happen if you modify the input to your program, but such thoughts can only be based on knowledge and we hope to accelerate the learning experience here.

This chapter describes the principles of gas turbine off-design behavior. Understanding these principles is the prerequisite of the effective and professional use of any gas turbine performance program. When you know something of how the gas turbine works, then you can ask reasonable questions of your performance program.

We begin with a look at the off-design behavior of some jet engine components and after that we describe how they work together.

2.1 Turbojet

The straight turbojet is the simplest gas turbine and it consists of the four main components—compressor, burner, turbine and nozzle, as shown in Fig. 2.1-1. Understanding the performance and component-matching of a turbojet is the key to understanding the behavior of the gas generator in any multi-spool engine.

2.1.1 Off-Design Behavior of the Components

2.1.1.1 Compressor

Figure 2.1-2 shows the map of a compressor. It describes how total pressure ratio and efficiency vary with spool speed and mass flow.