# SIMULATION-BASED FEATURES OF THE COMPRESSED AIR SYSTEM DESCRIPTION TOOL „XCEED™“

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## ABSTRACT

The XCEED™ software tool allows engineers to create textual, mathematical and graphical descriptions of compressed air systems including, but not limited to, compressors, filters, dryers, storage vessels, cooling equipment, piping and utilization equipment. The tool allows drag-and-drop creation of simulations of user-specified compressed air systems and provides engineering and financial calculation functions to aid analysis of such systems. In addition, XCEED™ provides standard report generation and allows user-developed reports. XCEED™ provides for decomposition of the compressed air system description by project/subproject taxonomy, allowing modular construction of the system description; top-level information for all subprojects is automatically created when requested by the user.

## INTRODUCTION

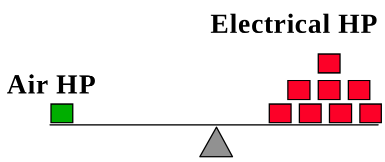
Compressed air is a significant utility used in buildings, manufacturing and process industries. Often this utility is not recognized for its energy intensity and is therefore undermanaged and/or inappropriately controlled and utilized. The subject of this paper is a compressed air system description and analysis software tool designed to aid engineers in capturing and manipulating information about an entire compressed air system, from production to utilization. The user may construct simulations, perform design and tradeoff analyses directly from within the XCEED™ environment.

Global competition among the world's major industries continually demands lower-cost production and higher productivity. For manufacturers, many of the large gains in cost and efficiency have already been realized in the production and product areas. Now manufacturers are searching for other value-added, mission-critical solutions to increase quality, lower cost and increase their competitiveness. In response to the need created by this trend, the industrial business unit of Honeywell H&BC provides performance-based solutions to business and industrial customers.

In the U.S., manufacturing accounts for over 30% of the total energy consumed. It is estimated that 10% to 30% of the total energy consumed in a typical manufacturing plant is for air compression. Air compressors are an integral part of manufacturing. For initial cost, safety, and reliability reasons, many machine tools in factories are powered by compressed air instead of electricity.

Electrically driven compressors require about 8 hp of electricity to produce 1 hp of usable compressed air power. Motor efficiency, thermodynamic losses in compression, and subsequent re-expansion of the air to produce motive power and air transmission losses contribute to air's high cost of power production.

The facility department within the manufacturing plant is usually responsible for the compressed air system and the production of the compressed air resource. Their customer for compressed air is the




production department. Typically, production departments are not held accountable for the compressed air they use. As a result, there is little incentive for precise control of compressed air utilization, and poorly chosen applications of compressed air power contribute to significant overconsumption of energy.

This savings opportunity exists primarily in the medium (26–300 hp) and large (300+ hp) compressor segment. This segment represents 16 million horsepower of total compressed air production capacity in the United States [1]. The cost of energy consumed for these compressors is estimated to be $7 billion per year. Energy experts such as Department of Energy (DOE) and the American Council for an Energy Efficient Economy (ACEEE) believe that roughly 30% of the energy used for air compressors can be saved through maintenance and retrofit solutions [2]. Assuming a conservative potential energy savings at only 20%, the total retrofit savings available is $1.4 billion per year. Typical return on investment (ROI) for compressed air system retrofits is 1–2 years [3].

## OBJECTIVE OF THE SOFTWARE

XCEED™ has been designed as an integrated toolset that will enhance productivity and reduce risks in the process of auditing, assessing, and quickly estimating improvement possibilities in compressed air systems. XCEED™ provides a level of site assessment risk reduction because it enforces a standardized information gathering and sharing methodology, applies standardized calculations to data supplied by the engineer, and acts as a single repository for data/ information.

The XCEED™ tool provides for collection and processing of information about a client's compressed air system (supply and demand) that will be sufficient to determine whether or not the particular site would make a good candidate for a retrofit. The tool is designed to provide information enabling a decision by the engineer to proceed with the project. It will aid in data collection, providing certain engineering calculations, formatting these data into standardized reports, and evaluating certain project metrics based on the data/calculations.

The simulation function of XCEED™ will be extremely useful in analyzing the transient phenomena of compressed air systems that arise from poor control policies and account for significant energy waste. Compressor controls, with their interlocks, time permissives and nonlinear behavior, create a dynamic interaction nightmare that does not yield easily to linear analysis. XCEED™ will significantly reduce the effort required to understand these interactions.

## CONTRAST OTHER SOFTWARE TOOLS

XCEED™ is unique in that it combines the auditing and reporting functions with dynamic simulation capabilities for compressed air system equipment and components. No existing tools are known to have similar functionality in description of compressed air systems; the tools partially approximating XCEED™ functionality would be piping analysis software, compressor specification aides (vendor proprietary), and certain auditing software specialized for compressed air applications; most of these applications are geared for steady-state analysis. Some representative examples, not intended to be a comprehensive list, are shown in Table 1.

## TECHNICAL BASIS

XCEED™ is written in Visual C++ and is delivered in Microsoft Windows® 95. Features of the tool (see Figure 1) are that it:

1. Provides simulation and display of compressed air system interaction using predefined compressed air system components;
2. Is composed of software objects representing physical components that contain the mathematical descriptions and data required by the simulation engine;
3. Simulates arbitrary compressed air system configurations (networks of pipes, compressor and equipment locations);
4. XCEED™ allows „super-users“ to create new or specialized component models;
5. Partitions large-sites into multiple subprojects;
6. Integrates with third-party software packages that provide simulation solver, drawing, word processing, spreadsheet and data-visualization functions.
7. Provides standardized reports and assessments of compressed air system features.
8. Integrates directly with data acquisition products for automated data download.

In the course of a normal compressed air job, the engineer needs to create multiple „views“ or representations of the client's facility. For example, the first view might be to describe the client's facility in its present state or „as-is“ configuration; the engineer would capture schematically the installed equipment arrangement and annotate the schematics with data describing the normal operating conditions. Later, as the engineer begins to formulate possible modifications that would improve the client's facility, the engineer would want to create modified schematics and annotations that would represent the facility in a proposed or „to-be“ state. The XCEED™ tool provides a way for the engineer to maintain several of these representations in the computer simultaneously. The XCEED™ tool provides this functionality through the use of „projects“ and „subprojects.“ In the above example, the „project“ would represent either the entire client facility or selected subareas of interest in the client facility; and the „subprojects“ would characterize the „facility as-is“ and „facility to-be.“ Figure 2 shows the XCEED™ Component Window within which the engineer selects and parameterizes the components to be added to project.

Projects are structured to allow for decomposition into subprojects so that multiple configurations of modeled compressed air systems can be compared and contrasted. These configurations may correspond to the pre-retrofit system and various versions of the potential retrofit. Each of these configurations will then be further decomposed into functional and physical elements. Functional elements will be categorized as previously discussed. Physical areas can also be hierarchically represented to break apart a large facility into one or more manageable areas. These areas correspond to facility-defined groups such as production lines, building wings, annexes, departments or other groupings. This functional and physical decomposition allows areas to be individually modeled and then combined into the complete air system consisting of:

- Supply side—compression equipment
- Demand side—air tools and equipment
- Auxiliaries—cooling, cleanup, etc.
- Energy—rates and rate structure
- Operations—procedures and costs
- Maintenance—procedures and costs

Schematic representation of the system elements (both functional and physical) are provided for all aspects of the compressed air system. The connection network produced by these diagrams provides the component interconnection information needed to define the air system circuit simulation (treating both serial and parallel elements). Each component „object“ contains references to a database of the mathematical description of the dynamics of the component required for submission to, and processing by, the simulation engine. Summarized schematic diagrams will also be used to provide a quick inspection of the overall system. Summary schematics are intended to show coverage, not detailed information, of the client’s compressed air system.

Engineering analysis tools are provided to assist engineer in the calculation/determination of compressed air system capacitance, mass properties, pressure drop calculations, and other engineering quantities. These attributes are further combined, via the schematic interconnection tool, into systems of equations relating the components; these systems of equations can be input automatically to an embedded simulation engine for simulation and „what-if“ analysis.

Financial analysis tools are embedded in XCEED™ to characterize compressed air system costs and determine a capital expenditure investment’s rate of return. This information forms the basis from which the engineer will be able to make retrofit suggestions based on simple ROI calculations. Project reporting features produce standardized documents that can be presented to clients as background materials from which the retrofit decisions are assessed. These describe the client’s air system in both textual and graphical forms. Problem areas are defined along with potential solutions.

XCEED™ provides interface functions to acquire data from data loggers placed strategically on the compressed air system equipment. Currently the user is required to download logged data from the sensing devices via a stand-alone software application running on a PC. XCEED™ provides for downloading such data directly into the XCEED™ tool itself; eliminating this intermediate step will reduce time on site. This information can be reviewed in both tabular and graphical formats. The engineer can associate the acquired data directly with the XCEED™ equipment objects in the project.

An animated demonstration of compressed air system supply and demand interaction is provided for communicating with the client. XCEED™ provides real-time data-driven displays of typical plant scenarios that allow the engineer to discuss with the client the physical reasons why a given system configuration performs as it does. This discussion is important in conveying the foundation of the energy-saving methods recommended. The demonstration scenarios are created using a simulation developed for XCEED™.

The demonstration, shown in Figure 1, consists of a small but representative complement of equipment that can be used to demonstrate 80%–90% of the types of problems seen in typical compressed air facilities. The dynamic demonstrations are based on a set of case study simulations chosen to describe selected phenomena of compressed air systems. The demonstration models two rotary screw compressors and a reciprocating compressor with cleanup equipment and a single refrigerated dryer. A storage receiver (compressed air storage tank) and system piping connect the compressors to the loads. Loads are modeled as time-varying flows, depending on whether they are regulated or unregulated, and may be pressure dependent as well. The demonstration window also supplies graphical images of gauges and meters to convey the state of the system in terms of the compressor power and flow, storage capacity depletion, supply piping pressure loss, and load consumption.

In the example shown, one of the most significant „events“ (not necessarily the most common) in a compressed air system has just taken place—a compressor has failed. The scenario describes the other compressors' activity to supply the load (see Figure 4). The case demonstrates that with different control strategies on the compressors, only the second rotary screw compressor would have been needed to satisfy the load, even with the loss of the first compressor—a significant energy savings.

Component models provide enough dynamic fidelity to model compressed air system transients to assess an existing system and explore potential modifications for improvement. Such modifications include compressor re-sizing and control law modifications, system storage capacity changes, load profile modifications, and active pressure control equipment additions. XCEED™ currently models the compressed air equipment described in Table 2, XCEED™ Component Models.

XCEED™ simulations are created by selecting compressed air objects from a Honeywell proprietary Visio palette of component choices. The Visio interconnection information together with the user-supplied object parameterization information (sizing, controls, ambient conditions) and simulation definition (duration, outputs desired) is used to define a database that is translated into ACSL executable simulation code.

## CONCLUSION

Honeywell Technology Center is developing the XCEED™ Compressed Air Description Tool as a productivity and risk-reduction mechanism for the Industrial Business Unit. The tool is built in Visual C++ and integrates with several third-party software applications. It allows standardized auditing, data acquisition, dynamic demonstrations of compressed air system phenomena, report generation, and specialized calculations, including system simulation and analysis, germane to the compressed air domain. XCEED™ will be deployed in late 1997.

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## FIGURES AND TABLES

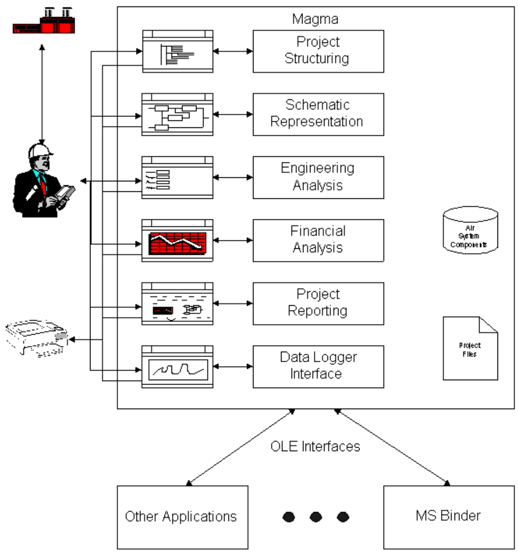


**Figure 1: XCEED™ Feature Set**

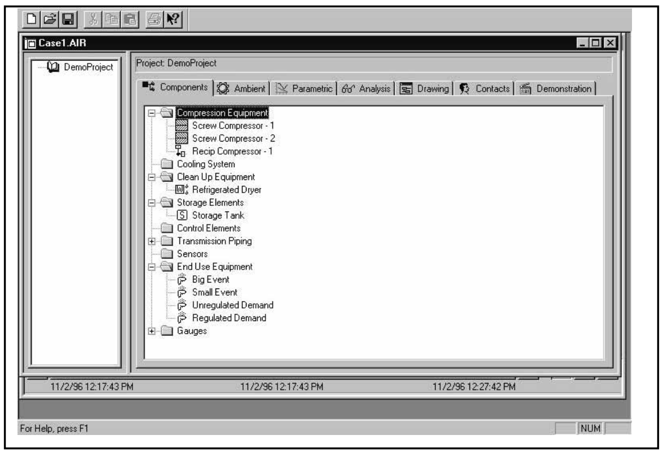


**Figure 2: Component Definition Window**

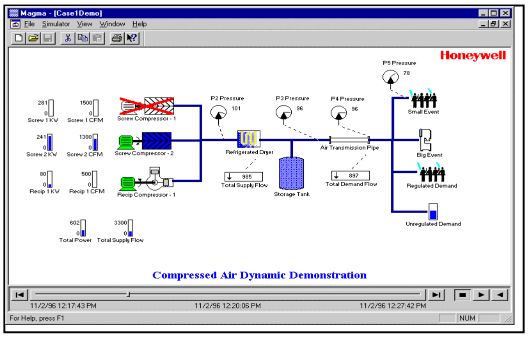


**Figure 3: Dynamic Demonstration Window**

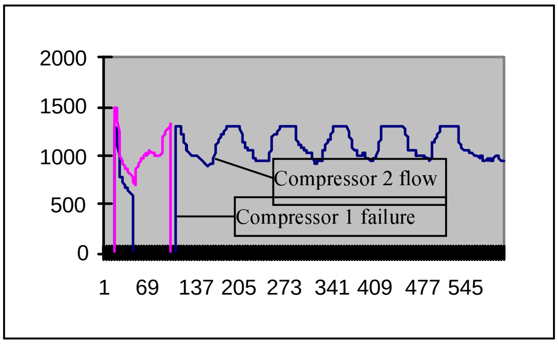


**Figure 4: Flow Response to Compressor 1 Failure**

**Table 1: Software Products Relevant to Compressed Air Domain**

| | |
|---|---|
| AirMaster—Oregon State University and Bonneville Power Administration | A spreadsheet-based auditing program that estimates existing and proposed compressed air system energy use and costs. |
| Compressor manufacturer sales support software— | Primarily these tools are for sizing compressor equipment and do not have capability for overall system representation or treatment |
| Engineer's Aide—Epcon International, Houston, TX | This tool is an integrated process engineering software providing an array of common engineering calculations and facilities for project documentation. Provides: pipeline/duct network sizing; pump/fan/compressor sizing; heat exchanger sizing; flowmeter sizing; control/relief valve sizing; conversion calculator; a fluid properties library; specification writer and project management features. |
| Pipe-Pro—Professional Designers and Engineers Inc., Boulder, CO | This software is useful for fluid flow analysis in piping design. There are 5 programs—liquids, gases, steam, two-phase and network. Solves for: pressure loss, flow rate, pipe diameter. |
| Flow Master III—Genium Publishing Corp., Schenectady, NY | The module FluidFlow is used to compute pressure losses and pumping power requirements for liquid flows in piping systems. The program analyzes piping runs in segments, each characterized by a given diameter and flow rate. Pressure drop or flow rate calculations for gas flow are performed using the module GasFlo. |
| HydroFlo—Engineering Software, CA | A parallel and series pump analysis software for smaller hydraulic systems that consist of only one source and one discharge but have up to 10 pumps operating in series or parallel. There are some databases built into the software—pump, liquid property, units and pipe specifications. |
| The Crane Companion—CRANE Valves, Joliet, IL | This is the software companion to CRANE's technical paper No. 410 „*Flow of fluids through valves, fittings and pipes*.“ This is a pipe sizing software allowing for global size changes (modification of entire branches instead of each component), component editing, enhanced orifice support.. |
| Automatic Pipe Sizing Software—CTS Engineering | Pressure-drop and velocity calculations are performed, an internal database of pipe schedules is used to determine the pipe diameter. |

**Table 2: XCEED™ Simulation Components**

| Component | Model Features |
|---|---|
| Compressors | Reciprocating and screw compressors modeled as positive displacement machines with stage control (recips 1,3,5 stages) and load/unload or modulation (screws).<br><br>Centrifugals—in progress.<br><br>All compressor models treat pressure-dependent power consumption. Compressors are modeled with state-dependencies to capture time delay dynamics of key permissives and interlocks. |
| Aftercooler | Pressure drop vs. flow. Thermal—in progress. |
| Dryers | Refrigerated dryer—Pressure drop vs. flow.<br><br>Cycling dessicant dryer—capacitance plus change-over for desiccant regeneration. |
| Storage (Receiver) | Simple capacitance model. |
| System Piping | Distributed capacitance and pressure drop; lumped parameter models. |
| Demand Expander© (a product of Honeywell-APT) | Equipment provides constant pressure drop at variable air flow; allows efficient storage at high pressure and utilization at low pressure. |
| Loads | Regulated—user-selectable time profile; no flow variation unless regulation limits are exceeded.<br><br>Unregulated—user-selectable time profile, flow varies with pressure.<br><br>User-selectable random variation of load flows. |
| Cooling/Heat exchange | (In progress—will model cooling towers, aftercooler heat exchange, auxiliaries' power consumption) |