Simulation Study of an Aircraft's Environmental Control System Dynamic Response

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Theme

A SIMULATION was made of the environmental control system (ECS) of a high-performance aircraft. The ECS provides temperature control for the cockpit and avionics equipment bays, throughout the flight performance envelope of the aircraft. This is achieved by bleeding hot air from the engine, cooling part of it, and mixing the hot and cold flows. The sensors, controller, and valves of the system were modeled, as well as the heat exchangers and expansion turbine.

The simulation was programed in CSMP, on an IBM 370/165 computer and operated over an array of conditions representative of the whole operational envelope of the ECS. Dynamic response was compared to specifications and sensitivity of performance to system parameters was measured. A partial evaluation of the simulation was achieved by using some available laboratory test results and comparing these with simulation results from the same conditions. The rationale, models, program, and results are presented in this paper.

Content

The environmental control system (ECS) of a high-performance aircraft is required to perform complex tasks. Consequently, it is complex in design. The ECS must supply proper temperature air to the cabin and to the avionics equipment, within the entire performance envelope of the aircraft and within the entire scale of external conditions of temperature and pressure. There are specifications on the dynamic behavior which require the system to stabilize within seconds and to not exceed specific inlet temperatures to the cabin and equipment which would be harmful to the pilot and to the avionics. Proper flow levels must be maintained and it is necessary that no severe pressure changes reach the cockpit, which would be uncomfortable to the pilot.

To verify the design of the ECS for a high-performance aircraft, a simulation was made which portrayed the dynamic performance of the system. It was intended to study stability, study sensititivity, identify possible problem areas in the design, and serve as a tool to evaluate the dynamic effects of any future design changes. A discussion of the system follows.

System Description. The ECS provides temperature control for the cockpit and avionics equipment bays, throughout the flight performance envelope of the aircraft. This is achieved by bleeding hot air from the engine, cooling part of it, and mixing the hot and cold flows. Transient changes into the ECS occur when the pilot alters the engine throttle setting and/or when altitude changes occur.

A functional flow diagram of the ECS system is shown in Fig. 1. The rate of flow of bleed air from the engine is measured by a venturi flow rate sensor, (20) and regulated by a controller and value (2). The flow is then split into two systems; one is cooled through heat exchangers (6, 12) and an expansion turbine (7) and the other is the hot air flow. These flows are mixed (5, 14) to provide cooling for the avionics equipment and after being dehumidified, (10) they provide temperature regulated air for the cockpit, (34, 18). In addition, there are devices to provide emergency shutoff, to override controllers, and valves are required to maintain flows and temperatures per design specifications. The cabin temperature is adjustable by the pilot within an effective range of 40 to 100°F.

The simulation model of the environmental control system was made in compliance with the design specification.[2] Some of the highlights of the dynamic performance requirements stated in the specification are: a) The temperature into the avionics (TAV) shall stabilize to within ±8°F within 10 sec after a transient input has occurred. Furthermore, the temperature transient overshoot shall not exceed 120°F. b) The temperature in the cabin (TCABIN) shall stabilize to within ±3°F of the pilot setting, within the capability of the ECS. (There are points in the flight regime where the ECS cannot achieve the pilot selection temperature). The TCABIN shall never exceed 200°F. c) The temperature into the water separator (TWSIN) shall be within the bounds of 33°F and 85°F and shall stabilize within 10 sec after a transient input has occurred. d) The pressures in the system shall stabilize to within ±2PS1 within 15 sec after a transient input has occurred. e) The flow shall return to normal within 4 sec after a transient has occurred and the flow into the cabin shall be within the bounds of 10 lbs/min and 48 lbs/min, within the capacity of the system. f) The valves shall stabilize, i.e., not fluctuate on limit cycle. Tests of these requirements were specified to be made with input transient variations of 50°F/sec and 100 PS1 sec.

General Simulation Approach. The general simulation approach was to develop mathematical models to represent the dynamics of the sensors, controllers, and valves in the system, and to calculate the flow rates, temperature, and pressure at various points in the system. To simplify the calculations, the physical representation of the ECS was divided into volumes and flows. Sections of pipe were lumped and the temperature and pressure in these volumes were calculated and the flow through valves was calculated.

Separate models of the heat exchangers and expansion turbines were also included. Assumptions: no limitations of linearity were invoked; the dynamics of the sensors were represented by transfer functions but limiters and slowly varying time constants were included as well; appropriate time lags were inserted for temperature changes in general, and for the heat exchangers in particular; and the time constants were held constant for the temperature changes even though a more exact representation would show them to be a function of flow rate. Furthermore, simplifying assumptions were made that no mass resonance effects and no friction or stiction of the valves was included.

Programming Considerations. When the math model was completed it contained a large number of differential equations and quite a few table look-ups: functions of one

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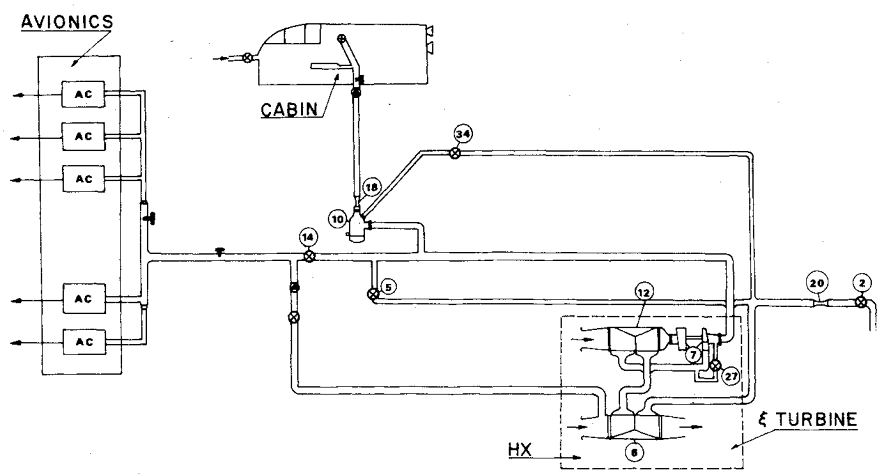

Fig. 1 Functional flow diagram.

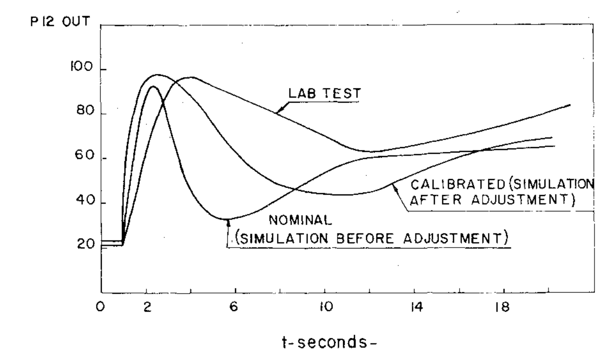

Fig. 2 P12 out (pressure out of heat exchanger) vs time.

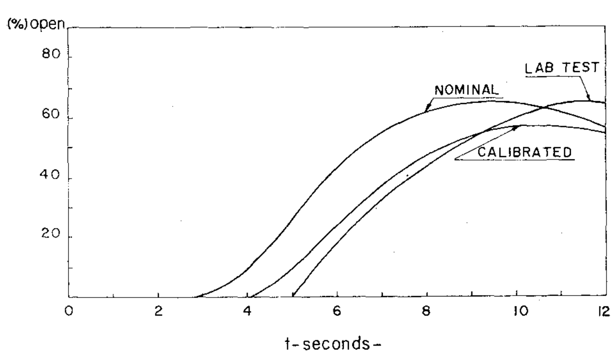

Fig. 3 A27 (valve 27) vs time.

variable and one a function of two variables, a number of limiters, and algebraic equations. The differential equations for the temperature delays, the control loops sensors, and valves were mainly first-order, second-order, and lead-lag types expressed in Laplace notation. The balance of the differential equations, i.e., the pressure rate of change equations, were first order. The total model involved about 1100 statements.

The math model was programed in five parts, according to the classification of types of subblocks: flow rate, temperature, pressure, sensor/controller, and the cabin. Each segment was programed separately and checked out with hand calculations. The total simulation was then checked further and after correcting some errors in sign, units, and initial conditions, the checkout was completed. At the same time, a selection of output parameters for printing and for graphing was made. The programing effort was substantially decreased by the simplicity and special features of the simulation language CSMP 111, notably its output of graphical results. In CSMP 111, all the transfer function "sub-blocks" in the math model were available in macro instructions in CSMP. After initially trying an Adams second-order and then a fourth order Runge Kutta integration routine, it was found necessary to use "STIFF" a special integration routine.

Verification and Comparison. "Steady-state" data existed for different initial conditions in the performance envelope of the system. To verify the simulation, several steady-state conditions of the ECS system were selected and a transition made to new steady-state conditions. In one case, a change in input pressure was made from 88 psia to 269 psia and of bleed temperature from 318°F to 410°F. The variation was made over 30 sec. It was found that the system transported from one steady-state to the other in a qualitatively satisfactory manner, within the dynamic requirements of the system. However, the valve action of the avionics and cabin hot side flows was greater than anticipated.

At this point, it was decided that it would be useful to compare the simulation with some laboratory measurements of the system made by the manufacturer for specific conditions.[1] This calibration comparison results in changes of the turbine time delay from 1 to 4 sec, and of the gain in the avionics loop from 0.0030 to 0.0013. Changes were also made in the cabin hot side valve dynamics. After making these changes, the two previous checkout case were run and they now showed good results, and compliance with specification. Figures 2 and 3 show the initial response, laboratory measurements, and subsequent simulation response for various parameters in the system. The simulation was then run for a series of sample points in the operational envelope and, to check sensitivity of the system to parameter changes.

Results. A dynamic response simulation of the ECS was made, checked out, and calibrated. The operation of this simulation over various points in the system envelope showed stable response, within the requirements of the system. The fears of inability to comply with system requirements and system instability proved unfounded in the regions studied and within the limitations of the accuracy and completeness of the simulation. It was shown that original estimates of time constants and time lags in this lumped parameter approach needed to be refined to bring simulation results into agreement with lab results. Once this simulation was checked out it became a tool for study of possible design changes and improvements and for analysis of new problems.

References

[1] "Design Approval Test Report," HSER 6148, Hamilton Standard, United Aircraft Corp., Windsor Locks, Conn.

[2] Shyken, N., "Engineering Specification, ECS," Rept. 4330/710/3383, IAI Ltd., 1972, Israel Aircraft Industries, Lod, Israel.