Engineering and Science Contract Group
2224 Bay Area Boulevard
Houston, Texas 77058

November 15, 2007
ESCG-4470-07-TEAN-DOC-0173

To: M. S. Anderson /NASA

Via: J. L. Cox /ESCG

Reviewed by: K. E. Lange /ESCG

B. C. Conger /ESCG

From: F. F. Jeng /ESCG

SUBJECT: Test Analysis Guidelines

Summary: Development of analysis guidelines for Exploration Life Support (ELS) technology tests was completed. The guidelines were developed based on analysis experiences gained from supporting Environmental Control and Life Support System (ECLSS) technology development in air revitalization systems and water recovery systems.

1.0 Introduction

Analyses are vital during all three phases of the ELS technology test: pre-test, during test and post test. Pre-test analyses of a test system help define hardware components, predict system and component performances, required test duration, sampling frequencies of operation parameters, etc. Analyses conducted during tests could verify the consistency of all the measurements and the performance of the test system. Post test analyses are an essential part of the test task. Results of post test analyses are an important factor in judging whether the technology development is a successful one. In addition, development of a rigorous model for a test system is an important objective of any new technology development. Test data analyses, especially post test data analyses, serve to verify the model. Test analyses have supported development of many ECLSS technologies. Some test analysis tasks in ECLSS technology development are listed in the Appendix. To have effective analysis support for ECLSS technology tests, analysis guidelines would be a useful tool. These test guidelines were developed based on experiences gained through previous analysis support of various ECLSS technology tests.

A comment on analysis from an experienced NASA ECLSS manager (1) follows: "Bad analysis was one that bent the test to prove that the analysis was right to begin with. Good analysis was one that directed where the testing should go and also bridged the gap between the reality of the test facility and what was expected on orbit". This comment points out the importance of understanding the developed technology and development of its model.

2.0 Pre-test Analysis

There are several steps that are important to the Pre-test Analysis:

Assist in developing goals and requirements for the test. This should be done as early as possible in the test planning. The analyst should consider what tests and measurements are needed to develop and validate technologies and their models. The analyst should also consider what technology and operational data are needed for potential trade studies. The selection of test environments and ersatz solutions is important at this stage.

Understand the test system - Obtain and understand detailed schematic, process and instrument diagrams (P&ID) and control logic of the test system. If essential components/ instruments are missing, ask the engineer/manager responsible for the test hardware to install the essential components / instruments.

Collect maximum hardware information up front. Collect detailed drawings of major components of the test. Collect or prepare performance information or curves for all major components of the test system, such as blower, pump, compressor, heat exchanger, adsorption units, instrument, etc. The following are examples of components and their essential information:

> Blower, pump, compressor – performance curves for the fluid mover.
>
> Conduct a relatively detailed hydraulics analysis (pressure drop) of the test system before the test. Always allow enough margin for pressure drop (say >15%) for unpredicted conditions. Make sure the system can take the pressure of the fluid driver when the fluid flow is accidentally blocked. Have the pressure relief set at this deadhead pressure.
>
> Temperature measurement – make sure thermocouples are the correct types for the expected temperature range.
>
> Heat exchanger – prepare heat transfer performance curves which can be used to check the performance of the heat exchanger.
>
> Heater – allow for heat loss to ambient in sizing.
>
> Thermal fluid – check vapor pressure and whether it is hazardous to humans if it is used in an open system.
>
> Set points of relief valves – use American Society of Mechanical Engineers (ASME) guidelines.
>
> Vacuum level – conduct detailed pressure drop calculations for ducts operated at sub-ambient pressure.
>
> Measure surface temperature of the hardware if an energy balance is essential – heat dissipation rate from the hardware has significant impacts on energy balance in crew systems.

Dew point measurement – dew point measurements often are erroneous. One technique to check dew point measurements is performing a moisture mass balance analysis of the subsystem.

Separation of liquid/vapor – allow enough residence time or use dynamic mechanism for separating vapor and liquid.

Assist test engineers in defining test parameters and their values, number of test points, and test duration. Operating parameter values include those in nominal operation and in contingency. Number of test points depends on available resources: budget, time, personnel. For a complex test task, a test design based on a statistical analysis should be considered. Test duration can be decided based on pre-test simulation results and initial function tests of the test system.

Collect desirable data measurements from parties involved in the test to make a complete data measurement list. Different parties may want different parameters for analyzing their unique functions. This is especially true for test projects involving multiple centers or institutions.

Specify data collection – test duration, number of data channels, data format and number of digits, measurement frequency, and available storage capacity.

Define desirable real-time data (pseudo) calculations with the required formula. "Pseudo" measurements are gathered from many channels or a combination (delta P from two pressures, etc). Other examples include Relative Humidity (RH) to dewpoint to ppH2O, heat load based on flow and two temperatures, etc.

Record test interfaces and facility parameters (vacuum quality, ambient air humidity levels, heat load from electronics not included in the test, surface temperature, actual sensor locations, etc).

Record parameters of test system environment (temperature, pressure, humidity).

Have a real time data dump, plotting software and computer at the test site. This can be very helpful for a quick check of the performance of components or the system.

Set up methods, macros, etc to process data files very quickly – set up macros to process data so a quick check of the performance of critical components or a quick review of the performance of the whole system can be done.

Develop a model (perhaps a simpler model in the beginning of the test) before the test and make sure it fits the test system. Refine the model as more test data are collected during the test program. Development of a rigorous model is always an advantage for technology development.

Predict test results using a developed model. Model predictions can be used for:

- Selecting components and instruments for the test

- Providing essential information for a test plan: such as test duration, test parameter values, number of test points

When conducting the energy balance of an air loop, don't overlook energy dissipation effects from a fan and energy effects from pressure drop.

Review operating conditions of vendor-supplied components. Different operating conditions will produce different operation results.

Don't take things for granted. For example, without an adequate fan circulation system the cabin air properties won't be uniform.

A system with simpler designs always is more dependable.

Allow appropriate margin for hidden or unpredicted conditions in all component sizing analysis; this applies to sizing of blower, pump, heat exchanger, heater, and reactors. Allow more design margin for components with more uncertainty, such as reactors.

The following technologies can be used to generate moisture for Air Revitalization System (ARS) tests: bubbling air in a water bath, directly heating water with a hot medium, passing an air stream through a water-flooded packed bed, dripping a water stream on a hot plot, etc. All have pros and cons. The challenges associated with these technologies include dew point measurement, transferring the generated humidity to the test system without condensing part of generated moisture somewhere along the path, and response time of steam generation.

Make sure low point draining of condensate is built into all air ducts.

There are commercially available software packages which display schematics and essential real time data on the schematic; this can be very helpful in monitoring a large test system.

3.0 Analysis during Test

Conduct leak checks of the test system – check to see whether there is leakage out from pressurized components or leakage in from external to sub-ambient pressure test systems.

Make sure the required conditions specified by component/instrument vendors are met to ensure reliable operations/measurements. For example, is there adequate vacuum for desorption or for sampling? Is there adequate cooling for the chilled mirror dew point meter? Is there enough air flow rate? Is the minimum straight duct length requirement between a flow meter and its nearest fitting met?

Check instrumentation precision and accuracy (location may play a role)

Humidity is difficult to measure accurately – check instrument accuracies and perform a mass balance calculation as a validation check.

Resolve problems or figure out why results do not meet expectations.

Make sure all measurements, such as temperature, pressure, concentration, are reasonable and satisfy common sense. Perform mass or energy balance calculations of the test system; it is one way to check measurement consistency. When most of the test data are in doubt, a duplicate test of the current test point should be considered as a method of validation.

Instrumentation or other problems can mean that results aren't perfect. Sometimes people believe the data when they shouldn't and other times people brush it off as instrumentation error when it is actually correct. Be suspicious of data, but try to figure out why it might be true (mechanisms not included in the model, etc.).

As knowledge is gained during the test, close the loop and go back to the model and make updates based on what has been learned, and ask for follow-on testing to explore new areas of need (off nominal, focus on a different process mechanism). New test points might be added at the end of current test series rather than waiting for a new test. The capability to quickly process a test data file, such as a spreadsheet model, is desirable so that the performance of the test system can be quickly analyzed and decisions regarding whether or not to add additional test points at the end of this series can be made.

Look for measures of consistency real time – ensure consistency and be ready to troubleshoot during test (bad sensor? leak?) Otherwise bad data will make the test sequence not useful.

When troubleshooting a pressure swing adsorption system, be suspicious regarding the pressure level in desorption beds; it may not be low enough because of external air leaking in. Be suspicious whether the adsorption bed is saturated with moisture.

Be suspicious of leaks at various connections when the test system is operated at sub-ambient pressure.

Tracking humidity in the air loop is challenging. Because the air temperature in the chamber may not be uniform, some moisture might condense. Make sure the air duct temperature or chamber wall temperature is always above the dew point, for example by heat tracing. A humidity mass balance (dew point measurement, steam/water balance) always is a challenging issue.

For water processing equipment, constituent mass balances should be performed. Ion balances (electroneutrality calculations) should also be performed for aqueous streams. These balances can help identify measurement problems and unexpected or unmeasured losses due to volatility or precipitation.

Review the performance of the test system setup. Is there modification/change of test hardware necessary to obtain better performance or better measurements, based on the test data?

4.0 Post Test Analysis

The purpose of post test analysis is to use the collected test data for validating and improving the developed model. Post test analysis also builds confidence in the model for use in evaluating flight conditions that can not be tested, or for predicting conditions that have not been tested.

In many test cases, the test data does not meet expectations and sometimes deviates significantly from the predicted results. The post test analysis goals include problem resolution, analysis of the test data, and/or figuring out why results aren't as expected.

Every deviation from model predictions has its cause. Finding out the causes and solutions, whether they are measuring errors or model deficiencies, is very challenging.

Data mining generates huge data files, and takes a lot of effort to analyze the data. Since test costs are significant, it is good idea to collect as much information as possible for later use. Good pre-test arrangement of the data collection helps.

When you learn something in the test, close the loop and update the model based on what you've learned. It is often beneficial to request for follow-on testing to explore things not previously investigated, such as off nominal or focus on a different process mechanism.

A perfect match between test data and model predictions is almost impossible. Due to schedule and budget considerations, model improvement should stop at a certain point where its prediction is within a tolerable limit from test results. The tolerable limit might be decided between the model developer and hardware developer or the user. In general, the fidelity of a technology model is driven by its intended use and by the importance of different phenomena that can be described by the model. The primary goal of any model is to obtain a fundamental understanding of the process.

Use help from experts. Many times excellent models might have already been developed by outside sources. Using existing and verified models in developing new models can significantly save analysis resources.

5.0 General Notes

Reference existing test plans, documents, test correlation efforts, etc. where available.

Two reports, a quick look test report and/or a detailed formal report, might be issued during or after the test. A quick look test report summarizing test results with preliminary conclusions could be issued during the test or shortly after the test; it can give management useful information to make early decisions. A formal test report is a document covering test data, analysis results, learned lessons, conclusions and suggestions and is typically used as formal reference document.

Good archiving and reporting are required when there are long gaps between tests or development cycles.

Frank F. Jeng

F. F. Jeng
Thermal and Environmental Analysis Section

References:

1. An email message sent from John Lewis/JSC on 10/24/07.

Appendix: Examples of Analysis Supports to ELS Tests

Development of 2nd generation Human Metabolic System (HMS) – Analysis work involved all three phases. HMS pre-test analysis included analysis of a human metabolic output model at various metabolic activity levels, trade study of various methods of oxygen removal technologies, fundamental analyses of sensible heat and latent heat addition, as well as mass and heat balance calculations. Analyses conducted during test and post test included test data analysis and hardware modification analyses.

Development of a two-stage mechanical compressor and development of an integrated Carbon Dioxide Removal Assembly (CDRA) and CO2 recovery system model – A team consisting of JSC, MSFC, Southwest Research Institute (SwRI) and Hamilton Sundstrand (HS) personnel were involved in the development of CO2 recovery technology and a two-stage mechanical CO2 compressor. Pre-test analyses included development of a rigorous CDRA model (by Lockheed Martin) and a rigorous compressor model (by SwRI). Pre-test simulations of the test system were performed using the models. Analysis support was performed in supporting numerous integrated CDRA and CO2 recovery tests. Post test analyses verified the CDRA CO2 removal model, CO2 recovery model and the mechanical CO2 compressor model.

CO_2 And Moisture Removal Amine Swing-bed (CAMRAS) facility setup support – Analyses were provided in calculating cooling/heating requirements to maintain the Air Revitalization Technology Evaluation Facility (ARTEF) at a desirable temperature range. Analyses also provided sensible and latent loads to ARTEF in simulating four/six crew metabolic loads in ARTEF at various metabolic activity levels. Analyses were performed in pre-test support.

90-day Lunar-Mars Life Support Test Project (LMLSTP) – Analysis was performed to support testing of closed-loop ECLSS technologies for an integrated crew cabin, plant growth chamber, airlock, and solid waste incineration unit. An integrated ECLSS system model was developed and verified with the test data. The integrated model simulated and predicted the performance of an integrated air revitalization system, water recovery system, plant growth chamber, human waste incineration system, and crew in the 90-day closed ECLSS system test. Analyses provided included pre-test modeling, test data analysis during test and post test analysis.

ELECTRONIC DISTRIBUTION:

M. S. Anderson	/NASA
M. K. Ewert	/NASA
B. C. Conger	/ESCG
J. L. Cox	/ESCG
K. E. Lange	/ESCG
F. F. Jeng	/ESCG

Task Order File Original + Copy