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INCORPORATING ENERGY CONSERVATION TECHNIQUES IN THE OPERATION OF EXISTING LeRC R&D FACILITIES

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ABSTRACT

A general discussion of various methods which can be used to reduce energy consumption in large research facilities is presented. A very brief description of Lewis Research Center facilities is given and the energy reduction methods are discussed relative to them. Some specific examples of the implementation of the energy reduction methods are included.

I. INTRODUCTION

The need to conserve energy in the operation of Lewis Research Center (LeRC) research and development test facilities has come into much sharper focus recently because of current national energy restrictions. This energy saving requirement is not a new one at LeRC but one that has become increasingly important in the last few years.

That energy cost savings have always been a goal at LeRC is illustrated by the fact that Cleveland was selected as the site for LeRC primarily on the basis of the availability of cheap off-peak electrical power. Two techniques which have been practiced since the major facilities were built fifteen to twenty years ago are: (1) maximum use of this off-peak power savings by operating the large power consuming wind tunnel drives almost exclusively at night and (2) careful meshing of the schedules for the various facilities which utilize the central combustion air and exhaust systems in order to cut the daytime peak power demand. More will be said of these techniques later.

Although energy savings have always been a goal, it has been only one consideration. Other considerations are the full utilization of facilities, the optimum utilization of manpower, the performance of test sequences within schedule restrictions, and the saving of energy.

It is now necessary to reevaluate this whole set of goals in terms of the greatly increased criticality of saving energy and energy dollars. New methods of operation must be instituted in order to effect the required energy reduction without undue impact on the other but still important goals.

It is the purpose of this paper to explore methods and means of energy conservation in the operation of the major R&D facilities at LeRC. In some respects, these observations will find general agency-wide applicability. The methods discussed make use of two general techniques; first, thorough planning of the operation and second, application of recent technology to increase efficiency.

The first involves restatement of a number of principles relating to design of the experiment which, though self-evident, must be closely reexamined now more than ever. The second involves application of new technology, such as modern microelectronics, which did not exist a few years ago. Though this second technique will be discussed at greater length than the first, it is by no mea more important.

The first portion of this paper is a general description of the salient characteristics of the major energy consuming facilities at LeRC in order to establish a sort of baseline for the remainder of the discussion. The next portion of the paper will discuss, in rather general terms, the methods now under consideration for energy reduction. The remainder of the paper will illustrate a few specific examples of the application of new technology to the facilities. These examples are, for the most part, presently being or about to be installed.

II. DESCRIPTION OF MAJOR LERC FACILITIES

In FY 75 LeRC consumed about 205 gigawatt hours of electrical energy. An approximate breakdown of this electrical energy consumption is 40% for the major R&D facilities, 20% for institutional uses (people comfort), and 40% for the multitude of minor R&D facilities. About half of the energy used by the minor facilities (20% of total) goes to drive the central air system. This paper deals with the 40% for the major facilities and the additional 20% needed to drive the central air system for use by the minor facilities.

Major facilities at LeRC fall into three general categories, wind-tunnels, engine test facilities, and engine component test facilities. A typical run of one of these facilities lasts from two to six hours with power drawn in the 30 to 180 Megawatt range. All of these facilities, except one, utilize and share a central air supply system consisting of a building full of compressors and exhausters and attendant humidity and temperature conditioning equipment. The one exception is the 10 by 10 foot supersonic windtunnel. It by itself however, is the single largest power load at the Center, drawing between 100 and 180 megawatts, and totaling 11% of the FY 75 consumption.

Figure 1 is an aerial photo of LeRC. Flagged on this photo is the Propulsion Systems Laboratory Equipment Building (PSLEB) which houses most of the central air system. The stars mark the locations of the major test facilities served by this air system. The two major propulsion wind tunnels are also flagged. These are the 8x6 foot tunnel which is served by the central air system and the 10x10 foot tunnel which is not served by the central air system. The Engine Research Building is flagged separately because it not only houses some major and many minor facilities but also the houses the remainder of the central air supply system.

Since these are R&D facilities, the prime goal of most tests is to gather data at the various desired operating points of the test hardware. Thus, the data gathering, handling, display and recording systems have a very significant impact on the running time of the facility.

A diagram of a typical data system in a typical facility is shown in figure 2. From 300 to 600 channels of steady state data are sampled at a rate of 20 channels per second, digitized, than sent over long lines to central recording and computing. Up to 200 channels of dynamic data (typically 50 to 100 channels) are also sent over long lines to the recording system in the computer center. In both cases, selected channels are tapped off for on-line control room readout on a wide variety of display equipment. In addition, some delayed display of computed results is sent to the control room. More in detail will be said of these systems later in the section on specific examples of applying new technology. It should be noted here that some few facilities are already installing modernized data systems but the majority are basically as shown.

Two significant features of LeRC operations which have been used for years to reduce the cost of energy are the reduction of peak demand and the use of off-peak power. Each week a meeting of facility managers and central air handling system operators is held. Its purpose is threefold; (1) to eliminate conflicts in test schedules of facilities competing for the services of the central air system, (2) to achieve the most economic use of provisions of the LeRC power contract by keeping the peak daytime power demand down and (3) to schedule the various facility running times for optimal deployment of support personnel. The resolution of schedule conflicts must make sure that, within the current operational status of equipment, air from the central system under the right conditions of pressure, temperature, humidity, flow, and flow duration will be available to the users at the scheduled run times. The second feature of LeRC power usage is the rather complex contractual relations with the local power company designed to minimize power costs by making maximum use of off-peak nighttime power particularly for the large power consuming propulsion wind tunnels. This usage is illustrated in figure 3 which shows the power versus time-of-day curve of the local power company both with and without LeRC. Noticeable on this curve is that a considerable fraction of the off-peak excess generating capacity is utilized by LeRC.

It should be noted at this point that energy cost savings are usually synononous with energy savings particularly in the case of electrical energy. The reason that off-peak power is cheaper is that the power company is operating only their most efficient equipment and hence burning less primary fuel per kilowatt-hour. Thus, only rarely must the distinction be drawn between energy cost and energy.

III. ENERGY REDUCTION METHODS

The measure of the efficient utilization of a facility must no longer be stated only in terms of hours run or data taken. It must be stated in terms of good reportable results obtained per unit of energy used to obtain them.

There are three methods by which the total energy required to conduct a given experimental program in a given facility may be reduced. These methods are to minimize:

1. The number of facility runs necessary to achieve the research goals.
2. The energy level at which the facility operates during each run.
3. The time required for each run.

They are all obvious but must be continuously examined in detail to determine whether they are being optimally implemented.

Each of these three will be examined in turn. The first two do not lend themselves to detailed discussion in a paper such as this because they each entail detailed knowledge of the specific facility and experiment. They will therefore be discussed in a rather broad philisophical manner. Some aspects of the third, reduction of running time, can be dealt with more generally without detailed knowledge of the specific facility and experiment. This is true because, armed only with knowledge of the kinds of facilities and experiments, quite specific recommendations on the application of new technology can be made which are generally pertinent.

A. Minimize Number of Runs

The key to minimizing the number of runs necessary to achieve the goals of a particular research program in a particular facility is what might be called iterative planning. The word iterative is used here to mean that the original test sequence plan must be open to constant revision based on the results of each run.

The original test sequence plan must be carefully laid out in order to determine just which data points must be obtained experimentally. This plan must require that maximum use of these experimental points be made by nonfacility running means such as analysis, interpolation, and extrapolation. It must then be recognized that, due to the research nature of the program, this original plan will undoubtedly be proved wrong after the first few tests. This is where the iterative process must be applied. The whole plan must be constantly revised to include what has already been learned.

A key element in successfully applying this iterative planning is the absolute necessity of having the results from one run in the hands of the planner in time to make an informed decision on the next run. The results necessary are usually the output of central computer programs working on data from the previous run. It is rare indeed that the planner has this information in sufficient time to plan the next run. When he does get the information it is after a couple of subsequent runs. He frequently finds that these runs would have been more pertinent to the problem if run at a different set of conditions or that he really did not need some of the runs at all. We feel that this is a most fertile area to improve in order to reduce the number of runs.

It may well be said that the foregoing discussion only points out the obvious. It does. It may also be said that everybody has always done this. They have. This discussion is only included to point out that this iterative planning must now be done more thoroughly and more consciously than ever before with energy savings at a much higher priority than before.

B. Minimize Energy Level for Each Run

Once established that a particular experimental run is necessary, the next step is to ascertain the run conditions and sequences which will draw minimum power and make maximum use of it. This might be accomplished, for instance, by the use of piggyback experiments. This means here that more than one experiment is conducted simultaneously during a run. As an example, it is quite possible that fan, compressor, turbine and/or other experiments might be conducted at the same time during an engine test program. Care must be taken in realistically using this approach so that the complexity of the run does not become so great as to jeopardize the quality of the results or the safety of the expensive hardware.

A concrete example of successful piggybacking at LeRC is at the 8x6 foot supersonic wind tunnel. This tunnel (see Fig. 4) uses a closed loop flow path. In a portion of the back leg of this loop is a 9x15 foot section which is very useful for certain acoustic experiments and low speed aerodynamic experiments. For about six years now the groups using the 8x6 section and those using the 9x15 section have been carefully coordinating their otherwise unrelated programs in order that both are running their tests at the same time whenever possible, thus using the same air flow twice.

Another very powerful tool is to make certain that the whole system used to generate the test conditions is operated at maximum efficiency at all times. At LeRC this means, for one example, that the central air system must be operated at maximum efficiency. To achieve this we must operate the generating equipment itself efficiently and also make certain that the air distribution complex is configured for minimum loss due to such things as inadvertently opened valves, leaks, unnecessary bypasses, etc. A more complete instrumentation system is being planned for this air system as a first step in peaking this efficiency. This instrumentation will enable the constant monitoring of each machine's efficiency so that the most efficient ones are used most often and so that timely maintenance can be performed on those machines whose efficiency has degraded. It will also enable the monitoring of flows both at the sending end and the receiving end in order to make certain that as little as possible is being lost in leaks, etc. The instrumentation can also form the basis for possible further automation of the system if this proves desirable and necessary.

Only a few examples of techniques to reduce the power level during a run have been cited here and they have been rather tailored to LeRC type facilities. The reader, familiar with his own situation, can certainly apply the general principle to his own facilities.

As in the previous section, these are all obvious types of techniques which have always been well known. Again we must reevaluate them in light of the energy critieria.

C. Minimize Running Time

Once established that this run is necessary and that the planned operating power level is optimum, the remaining technique available to minimize total energy is to keep the run time as short as possible. To do this, one must examine the various components of operating time such as startup and shutdown, data taking, changing test conditions, decision making, and troubleshooting.

A recent attempt to determine typical percentages of running time devoted to each of these components turned up some very interesting information. The data reported showed, as expected, that there is a great deal of variability in the percentages from facility to facility and even from one type of test to another in the same facility. For example, dynamic data taking time (i.e. time to set recording system scale factors, to record, etc.) ranged from zero to fifty percent of the total run time in the same facility for various types of test. Nevertheless, some reasonable generalizations could be reached. Steady state data scanning is normally about 10%. Startup and shutdown runs about 30 to 40%. Changing conditions and dynamic data taking make up the rest. These are the results reported for a run during which everything goes smoothly.

The most significant result of the survey is that in reality such smooth runs are rare indeed. Troubleshooting and decision making time in fact consitute from 20% to 60% of all running time during most runs and hence form a major energy drain which must be reduced. The fact that troubleshooting and decision making must be done on-line is not surprising in light of the research nature of the experiments and the complexity of the equipment used. The very definition of research implies that the experiment involves the testing of hardware whose characteristics are imperfectly known at best. The fact that troubleshooting and decision making take so much time is surprising. We are convinced that one of the major attacks on running time must be directed at these two components.

At first glance it might be thought that the most efficacious attack on decision making would be the careful preplanning already discussed. While this planning is valuable and necessary, it must be recognized that the unexpected frequently occurs during a run and that on-line decision making must be done. The attack must be primarily in the form of providing the operators and researchers with information necessary to make quick decisions. This information must be on-line, virtually real time, and presented in a human engineered manner to optimize both the understanding and realization of what is presently going on. Only by doing this can the operators make timely and rapid decisions such as whether the data just taken is valid, whether to stay on this test point or move to the next, whether conditions have sufficiently stabilized at the new test point, etc.

This is an area where great strides can be made using the recent advances in data handling, calculating, and display technology. (See section IV-A "Dedicated Computers and Displays" for example.) Systems can be implemented which are quite generally applicable to all facilities and thus only a minimum of facility-specific engineering is required. The result is thus a large return in reduced running time per unit of design invested.

Reduction of troubleshooting time lies primarily in making certain that the equipment is fully functional prior to actually running the facility. (See section IV-B, "On-line Transducer Calibration" for example.) This can be accomplished in part by utilizing the same technology as mentioned above to automatically, rapidly, and thoroughly check out the equipment to be used. This should be done primarily before the run but can also be done to a limited extent while running. Certainly the confidence achieved in the validity of the data being taken will eliminate a great deal of the "take another point to be sure" running time.

Reduction of steady state data scanning time is probably the simplest task, at least at first glance. If the survey results, previously discussed, are at least roughly true, a fast scan of the steady state data would cut nearly 10% of the time out of running. (A very rough calculation, based on this for LeRC yields about a 10 gigawatt hour saving.) This can be accomplished with existing off-the-shelf scanning equipment which typically samples at least 1000 channels per second as opposed to the present 20. Great caution must be exercised in applying this technique to avoid subtle pitfalls. It involves much more than just plugging in a new scanner. Consideration must be given to such things as; (1) ability to record at the new speed, (2) dynamic response of sensors and pressure tubulation, (3) rejection of noise and hum on the sensor lines, and (4) other problems which can arise under certain specific facility conditions. These are all soluble problems but must not be forgotten. Neglect of them can result in poor quality data which is obviously inimical to getting "good reportable results" per unit of energy.

Reduction of start-up and shutdown time as well as reduction of changing test conditions time are not as amenable to generalized solutions. Though they will be impacted somewhat by the modernized data handling as discussed in the previous sections, they are very dependent on factors which are difficult or uneconomical to change. These portions of the running time are controlled primarily by the thermal, mechanical, and aerodynamic time constants of the facility, test, and generation equipment. They are also set to some extent by the rates at which load can be taken on or shed by the power company. While certain improvements can be and have been made in specific cases, large overall improvements would entail immense facility redesign at unacceptably high cost.

In summary then, the minimization of running time, can be accomplished primarily by the application of modern equipment to enhance on-line data display to the operator, thereby minimizing the evaluation and decision making time, and to speed up the data gathering.

This may all sound as though full automation is being proposed. In most cases it is not. Care must be used in the application of automation to research facilities. The very nature of research is that the same test is seldom run twice. Too great an attempt at automation can result in more running time being used to debug the automation than is saved in the actual test run. What is being proposed here is a certain level of automation of the measurement and data systems rather than automation of the whole test. On the other hand, full automation may well be worthwhile for the central air system because it more nearly resembles a production process facility than a research facility.

The remainder of this paper will deal with a few specific examples of individual projects aimed at implementing some of these generalities.

IV. SPECIFIC EXAMPLES

In this section a few specific examples of programs which impact facility running time will be discussed. They are either presently being implemented or are at least very seriously contemplated at the time of writing. Many of them had as their original goal the savings of manpower but it became evident at the inception of the energy crunch that energy savings will probably be the prime benefit. The selection of examples is primarily an attempt to give the flavor of the programs rather than a complete catalog.

A. Dedicated Computers and Displays

This paper has frequently referred to the new technology which will have such an impact on running time. The new technology referred to is primarily that of the small computers (both minicomputers and microprocessors or microcomputers) and computer related electronics. Systems which only a few years ago were impractical from a cost, complexity, and software standpoint are now very reasonable and in fact necessary from the energy conservation viewpoint.

A program is presently under way to transform the steadystate portion of data systems in the major facilities from the configuration shown in figure 2 to that shown in figure 5. The salient changes are the inclusion of multiple microprocessor control of various special instrumentation, a fast scanner for standard instrumentation, a dedicated minicomputer, and an on-line CRT display of calculated parameters. The principal guidelines in the implementation of this type of system are:

1. Optimize the operator to data interface via the on-line calculated display. This will grossly reduce decision making time.

2. Maximize the automatic checkout of the system off-line to reduce on-line troubleshooting time.

3. Speed up the whole process of pre-run setup of the system and during-run operation of it.

4. Make optimum use of inexpensive microprocessors for the care and feeding of special instrumentation so that the minicomputer software is simplified. (A few examples of special instrumentation are Scanivalves, infrared pyrometers, on shaft data systems, transient analyzers, spectrum analyzers, etc.)

The last guideline is a particularly significant one. We at LeRC are well along in applying microprocessors to steady-state data systems. Attempts are now being made to apply the same principals to the dynamic data systems, but this has not evolved sufficiently at this time to say much about it. It is certain that some of the recently available equipment such as fast fourier analyzers, digital transient recorders, and calculating oscilloscopes will fit the scheme beautifully. It is important to keep abreast of what is available. Little invention is needed. Careful, innovative application is essential.

One roadblock which must be anihiliated is the present restriction in the procurement and application of computers. To be sure they are capable of being misused but so also can any other item of equipment. If we are to truly take advantage of their immense capabilities we must learn to treat them not as some very special kind of equipment but as just another link in the chain of boxes necessary to do a job. Computers are with us to stay and are rapidly becoming ubiquitous. All must either learn of the computer's capabilities and limitations or face rapid obsolescence. No longer can a computer be looked on by some people as an infinitely capable device worthy of near worship on one hand, and by others as a device so somplex and demonic that it must be feared and avoided, on the other hand. Both attitudes are equally wrong and, until they are eradicated, progress will be difficult.

B. On-line Transducer Calibration

In order to avoid repeat runs, with the attendent energy consumption, it is essential that the transducers in use and their calibration constants be reliable. This consideration is particularly pertinent to strain gage type transducers such as those used to measure steady state pressure in a transducer per channel configuration.

The present method of operation depends on calibration data for these transducers which is obtained from a central calibration facility long before the run. In addition, the implementation of this scheme requires two critical, manual adjustments of the electronic signal conditioning box for each transducer just prior to each run. These adjustments are for the zero of the transducer as determined by the pre-run zero pressure input and for the span of the transducer as determined from the previously obtained calibration. In some cases, because of the large number of transducers, these adjustments take hours to make before a run. The probability of error, not to mention the manpower requirements, make this system difficult to defend if there is a better way.

There is a better way. We are presently developing a system whereby the transducer will be calibrated against a secondary standard transducer on-line, during the run, at the operator's (or the computer's) discretion. The key to this is a reliable low cost valve which will be used to connect two calibration pressures to the transducer (near zero and near full scale), as measured by the secondary standard, whenever calibration is needed. The secondary standard is just another input to the data system. The computer can then take this two point calibration data and make on-line corrections to all readings or it can code out transducers which have failed. In addition to providing this on-line credibility enhancement, this system eliminates the need for all manual adjustment. The implementation of this scheme will probably utilize another dedicated microprocessor to carry out the calibration sequence for all the transducers and feed just the results to the minicomputer. This will be done to keep from complicating the minicomputer software.

We are quite certain that this system will eliminate an appreciable number of facility runs because of the enhanced reliability of the data.

C. Other Examples

The following is a list of some of the actions which have been taken in the two propulsion wind tunnels (10x10 and 8x6) to reduce energy consumption. It is excerpted from a 1973 memorandum from the Chief of the Wind Tunnel and Flight Division to the Director of Technical Services (who is also the LeRC energy coordinator). These actions took place over the time period from 1969 to 1973. This list is presented primarily to illustrate (1) the wide variety of actions which impact energy consumption in these facilities and (2) the fact that energy consumption has been a concern for many years.

1. Installation of solid-state control systems to improve the setting of test conditions including the 10x10 heater and coolers and the 8x6 tunnel pressure ratios.

2. Provide computer scan and control of precision reference pressures for the Scanivalve system in the 10x10.

3. Automatic recording (instead of manual) of gain changes for different pressure levels during the run for both the 8x6 and the 10x10.

4. Provide data logger (on paper tape) to record parameters used to monitor tests in the 10x10 thereby eliminating hand recording.

5. Move the flexible tunnel walls of the 8x6 five times faster with a new hydraulic system, saving a significant portion of run time.

6. Optimize pressure-measuring geometry, using a computer, to minimize settling time for each model.

7. Provide automatic step-change control for multi-point tests.

8. Provide a central console for the 10x10 which consolidates the displays which aid the test conductor in making decisions.

V. CONCLUDING REMARKS

In conclusion we would like to reemphasize that the most significant action to be taken to save facility runs and running time is to get the right information to the right people in sufficient time to make timely decisions. This goes equally for both on-line information during a run and off line information between runs. An additional point worthy of restatement is that great care must be excercised in automating research facilities. Some of the experience gained from the automation of production facilities can be applied to research facilities but only after careful consideration of the nonrepetitive nature of research facility use.

To be sure, the emphasis on energy reduction has risen dramatically, but the concepts upon which the approaches are based have been churning around for a long time. Today's critical need for energy reduction is providing ample justification for the actual implementation of these concepts. Energy reduction must not be considered a threat but a challenge.

The author wishes to acknowledge the contributions of Mr. Calvin Lovell, Mr. William Rowe, and Mr. Robert Bercaw to the formulation of the ideas in this paper.

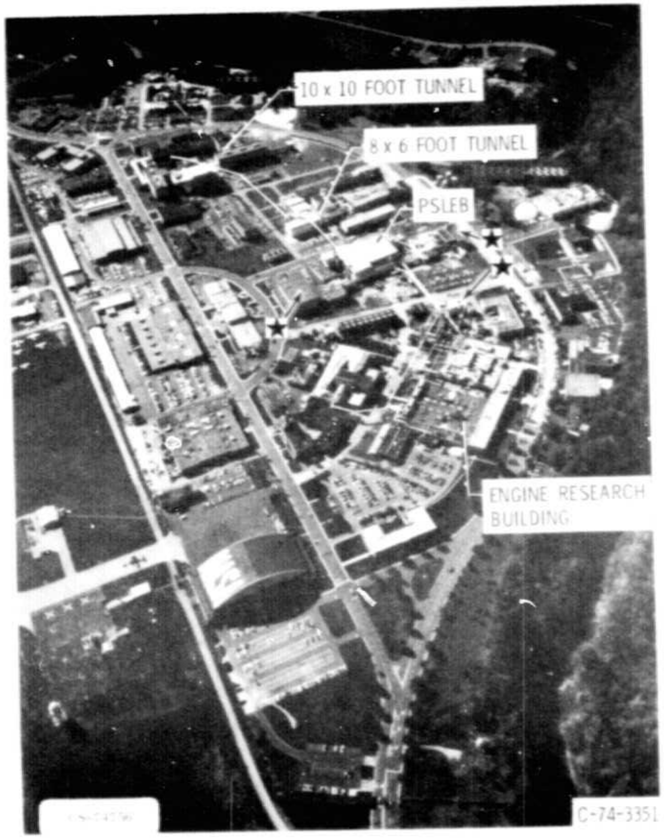

Figure 1. - Lewis Research Center; physical plant.

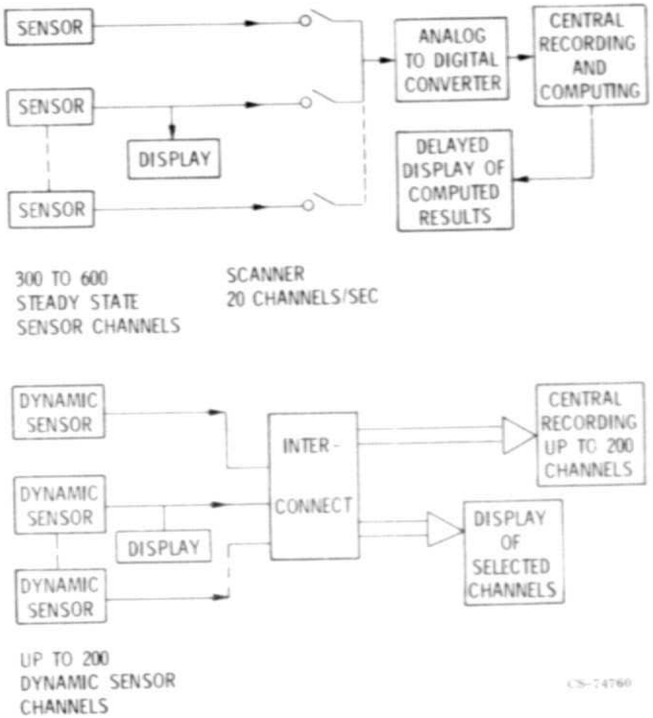

Figure 2. - Typical present data system.

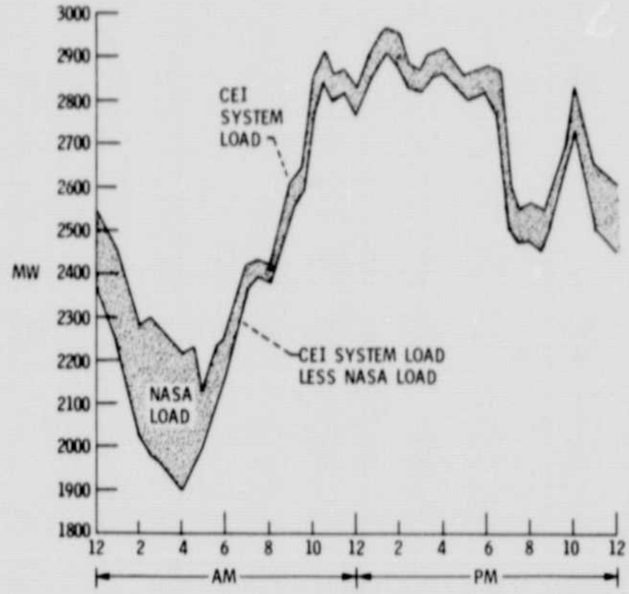

Figure 3. - NASA load soars after midnight and fills CEI's system off-peak valley. Chart showing how NASA-LeRC electric load complements CEI's system load.

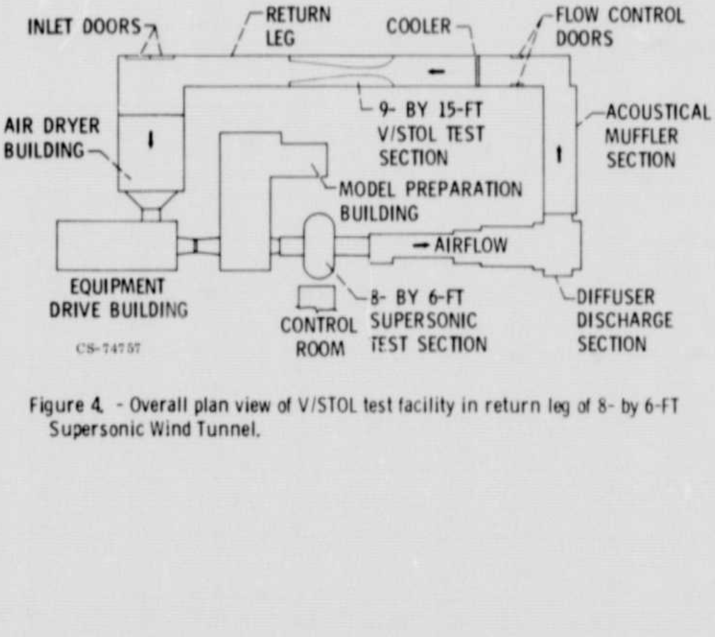

Figure 4. - Overall plan view of V/STOL test facility in return leg of 8- by 6-FT Supersonic Wind Tunnel.

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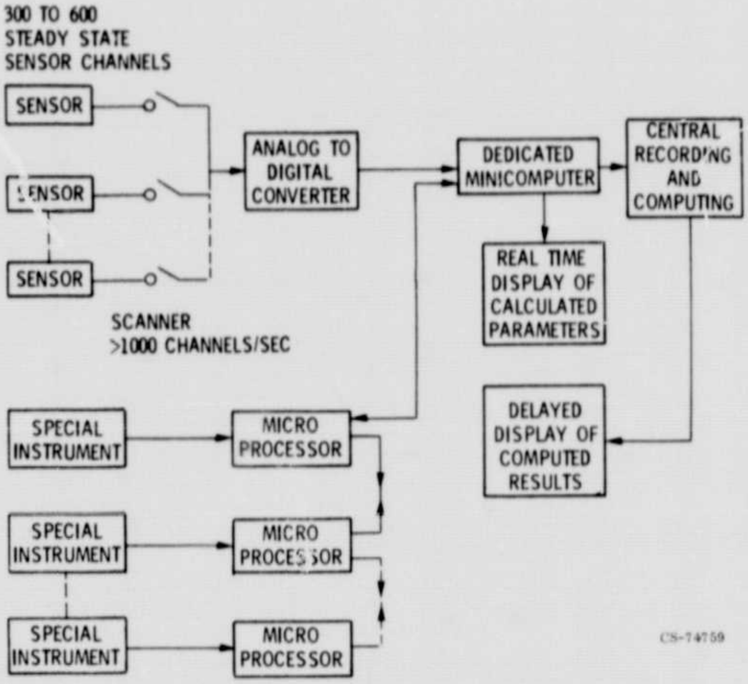

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Figure 5. - Typical proposed data system.

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