TESTING 2000

Wind Tunnel Testing
in the
21st Century

The ideas and concepts presented here represent the contributions of many people, both within industry and NASA. They have been collected and cast into a reasonably coherent paradigm by:

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1997

INTRODUCTION:

The aircraft development process is undergoing revolutionary changes throughout the U.S. aircraft industry, both in the development of commercial and military aircraft. The commercial aircraft developers are being driven by the combined requirements of bringing superior aircraft to the market place quicker and at lower cost than their competitors. The military aircraft developers are being driven by the requirements to develop technologically superior aircraft in a time span that allows that technological superiority to be advantageous to the military and to develop that aircraft system at the lowest possible life cycle cost. Historically commercial and military aircraft development programs have been very disimilar, but they are now being driven by essentially identical requirements.

As both industry and govenment struggle to adapt their processes to meet these new requirements, the aircraft design teams are beginning to admonish the wind tunnel test organizations to: **"Quickly conduct wind tunnel tests that provide the right data whenever a test is needed".** Although one could question whether this is a new requirement, careful examination of the changes in wind tunnel testing that will be required to respond to this admonition will reveal that truly revolutionary changes must be made in every aspect of the wind tunnel testing process.

TESTING 2000 is an acronym for a set of ideas and concepts, a new paradigm, that would responsive to the requirement to quickly conduct a wind tunnel test cycle. It focuses primarily upon the quickly portion of the admonition. Although some elements of TESTING 2000 are applicable to the other two key words, **right and whenever**, these later key words will be addressed seperately. Obtaining the right data requires that data accuracy requirements be met and that the testing processes and the expertise of the total test team meet certain standards. Conducting a test whenever it is needed focuses upon the management and cultural philosopy of the wind tunnel operations.

Before describing the ideas and concepts of TESTING 2000, it is helpful to discuss the driving forces which are requiring that changes be made in the total testing process. Currently, as shown in Fig. 1, about six years are required to bring a new aircraft into the marketplace. This span of time starts with the decision to offer a new aircraft to customers and is completed with the delivery of the first aircraft to a customer. The stated goal of industry is to halve this time, and NASA has adopted this same goal as one of the 10 goals of its "Three Pillars for Success". Although the goal of halving the aircraft development time will require major changes both the Product Definition and Product Development phases, some industry visionaries are beginning to extoll the economic and competitive advantages that would come from reducing the overall aircraft development time from six years to one year. If this capability could be achieved, the concept of customized aircraft for each customer could become a reality, greatly increasing the number of models that would be developed, and more than likely, greatly increasing the amount of wind tunnel testing that would berequired.

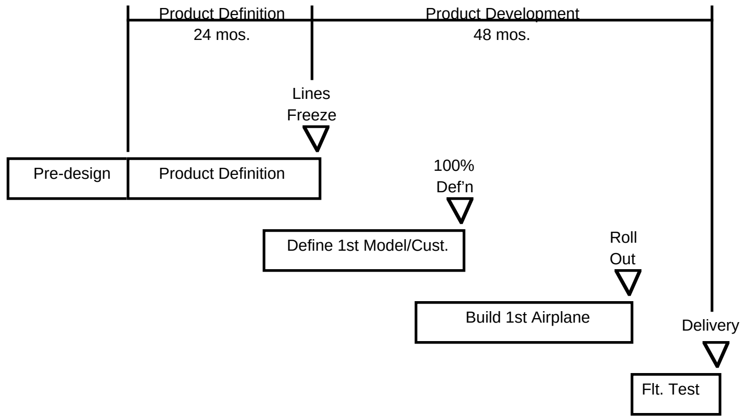

Fig. 1 Typical aircraft development cycle.

Many improvements in the design, testing, and manufacturing process must be made to achieve industry's goals. The traditional roles of configuration design and wind tunnel testing are imbedded in the "Product Definition" phase. The product definition phase typically consists of three discrete cycles, spread over a period of 24 to 30 months, as shown in Fig. 2:

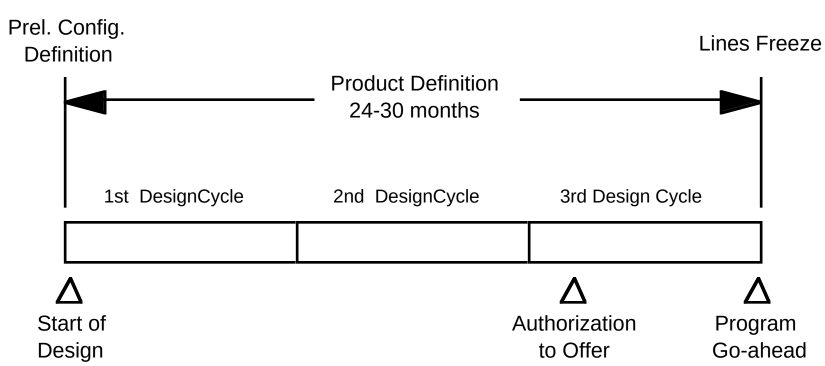

Fig.2 Current product definition cycles.

In order to meet the requirement of halving the aircraft development time, the product definition phase must be reduced by two-thirds, as shown in Fig. 3:

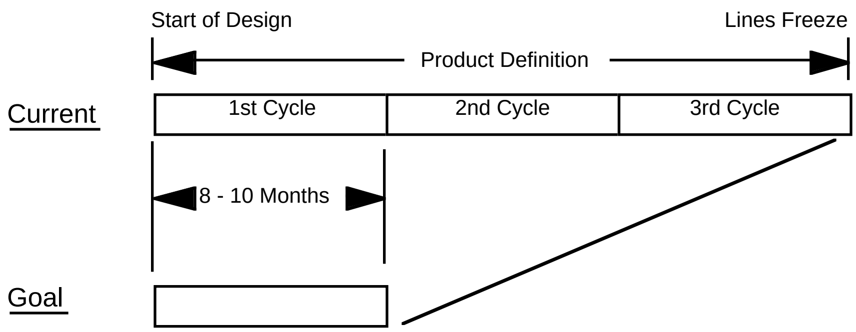

Fig.3 Goal of shortening product definition time.

Within the Product Definition phase, each individual design cycle can be broken down into its components as show in Fig. 4:

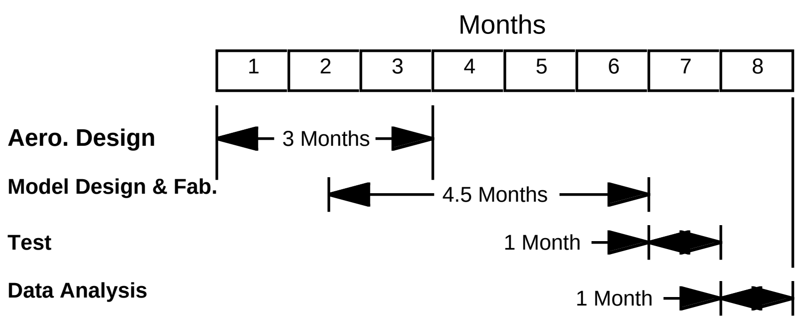

Fig. 4 Details of a current design cycle.

If a Wind Tunnel Test Cycle is defined as consisting of the Model Design and Fabrication, the actual Wind Tunnel Test and the Data Analysis, the time to conduct a wind tunnel test cycle is seen to be about 6.5 months. Unless something is done to drastically reduce the time to conduct a wind tunnel test cycle, it will essentially consume the eight months that can be allotted to Product Definition. To fit into the reduced time allowable for Product Definition, at least a 6-fold reduction in the time to conduct a wind tunnel test cycle is required.

TESTING 2000 -- some ideas and concepts, a new paradigm, on how wind tunnel tests must be conducted in the next century.

Current market surveys predict a market for 16,000 commercial transports over the next 20 years, at a total dollar value of $1.1 trillion. In order for US manufacturers to control a major market share, they must be able to bring a superior products to market, quicker and at lower cost than their competitors. As noted in the introduction, currently about 6 years are required to bring a new aircraft to market, from initiation of the project to certification of the aircraft. Of that time about 1/3 is consumed by product definition. Boeing has stated goals of halving the time to bring a new aircraft to market, and of reducing the product definition phase by about 2/3. With everything else being held constant, reducing the time for product definition by 2/3, would provide about a 25% reduction in the total delivery time for the first aircraft. In order to achieve a reduction of 2/3 in the product definition time, it is absolutely necessary bring about about a 6-fold reduction in the time required for a wind tunnel test cycle. This would shorten the time from about 6 1/2 months to 30 days for a traditional continuous test, or generate the capability to conduct high-frequency tests of a couple of days duration on about 2 week intervals. Both of these times would include model manufacturing or modification. This reduction in time for a wind tunnel test cycle is shown in the following two figures, Fig. 5 and Fig. 6 for a continuous test and a high-frequency test respectively:

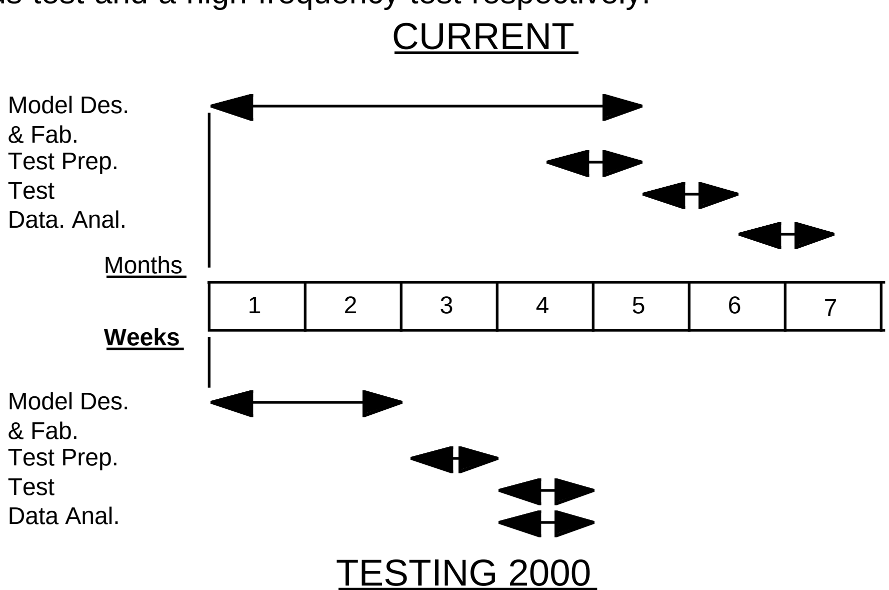

Fig. 5. Continuous test

Note the time scale change from months to weeks and the simultaneity of testing and data analysis.

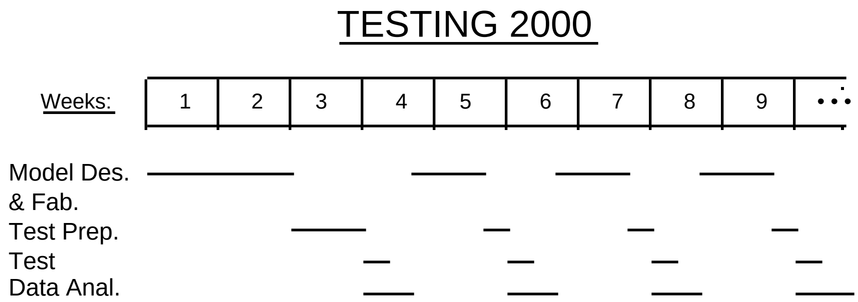

Fig. 6. High-frequency test

TESTING 2000 is a concept for future wind tunnel testing that would provide capability for very short continuous test, or a series of high frequency tests and is believed to be responsive to the needs of industry for either commercial or military aircraft development. The general idea is to implement processes, procedures and equipment that will enable high-productivity, high-frequency testing without sacrificing either the amount or quality of the data obtained during a test.

In order to implement a new paradigm, such as TESTING 2000, for wind tunnel testing, many of the current practices and procedures of wind tunnel testing will have to change. There are some things that are absolutely critical to the success of TESTING 2000, there are other which are of generic sustaining value to wind tunnel testing, and there are other elements which will add value to wind tunnel testing and particularly the relationship of wind tunnel testing to other aspects of the configuration development process. All of these elements are listed below, followed by a detailed description of each element.

TESTING 2000

CRITICAL ELEMENTS

- Improved business practices
- Just-in-time testing processes
- Dedicated test team with customer oriented attitudes
- Intelligent agents for test planning
- Remote access model design and manufacturing system
- Rapid data reduction program development
- One-day balance calibration capability
- Rapid installation - deinstallation of models
- Virtual interactive control rooms at user site
- High-speed, near real-time data acquisition systems

- Institutionalized advanced instrumentation and test techniques
- Overall high facility productivity

GENERIC SUSTAINING ELEMENTS

- On-line, real-time data uncertainty analysis tools
- Thorough, detailed facility calibrations
- Flow quality consistent with customer requirements
- Quick-installation calibration models
- Customer oriented metric capability and testing processes

ADDED VALUE ELEMENTS

- Current-aircraft data bases
- Information systems for aerodynamic knowledge
- Real-time aircraft design tools
- Information management systems

CRITICAL ELEMENTS --

• Improved business practices. At the current time, the time to prepare the contractual agreement to conduct a wind tunnel test for fee far exceeds the time that will be scheduled for the entire wind tunnel test in the future, including building the model. In addition the final cost of conducting the test is not determined until sometimes months after the completion of the test. To meet the requirements of rapid testing, prearranged contractual agreements will have to be developed and each user given essentially what amounts to a credit card. When he starts a testing process, he begins to accrue costs against on that card, and upon the completion of the test, he will be billed for the cost of the test. In addition, the accounting systems must be improved such that the user knows, in very near real time, what the costs are accruing for the test. (This could be a readout on the benchboard.) The current practice of requiring users to send a check to the Government test site before the test can begin is another ridiculous Government regulation that must be changed. The attitude always seems to be that the Government trusts no one, but that everyone should trust the Government. Once a line of credit is established, tests should begin as soon as they are ready. Essentially the user puts his credit card in a slot on the benchboard, and the test begins.

• Just-in-time testing processes. Just in time testing deals both with the way we schedule tests and the way we conduct tests. In the future, we will have to be flexible in our scheduling to meet the short term requirements of industry's dynamic design process. As industry's time for product definition shortens, they will need access to the facilities essentially on demand during that time period. This will particularly be true in a high frequency testing mode wherein the wind tunnel is being used as an iterative design tool during a period of short, 2-3 day, entries at intervals of about two weeks. Wind tunnel scheduling processes will have to recognize this need and be able to respond, almost in real time to request for entry into the facility. Ideally, we will have to develop the capability to perform all of our scheduling over the internet, since the time for users to travel and make formal presentations for a test will not be compatible with a short product definition cycle. Just-in-time testing will also necessitate developing the capability to interrupt a test in progress that may be lower in national priority for a test that has higher priority. As we develop the ability to conduct tests much faster than we currently do, this will become less of a problem, but we must develop the physical capability and mental outlook that will enable tests to be interrupted. The capability to install and deinstall models in a very short time is an enabling capability for just-in-time testing.

• Dedicated test teams with customer oriented attitudes. Successful service organizations spend a lot of time finding out their customer's requirements and exceeding those requirements.. In addition to understanding the technical requirements of our customers, we will have to understand what services and attitudes they want from the wind tunnel operators. In an environment wherein a greater portion of the testing process will be done over the internet with customer involvement at remote sites, the local test team has an increased responsibility to act as the on site agents for the users. This will require an unprecedented level of dedication from the test teams to essentially be an integral part of the users design team. For all practical purposes, for the duration of the test program, they must support the test with the same dedication they would have if they were employees of the customers. Developing this work attitude in a heterogeneous staffing mix of civil servants and contractors at government test sites will be difficult and will require cultural and mangerial changes. It should be relatively easy to convince the contractors that there livelihood and potentially survival depends upon the satisfaction of the users, but the same level of motivation among the civil servants will not be easy to cultivate. Some combination of survival, pride, rewards, and even patriotism will have to be used to motivate the civil service work force.

• Intelligent agents for test planning. If the goal of conducting a wind tunnel test in 30 days is to be realized, then the test planning process must be accelerated, to the point that all planning for a test takes place in about one week. Many of the tasks of conducting wind tunnel tests are repetitive in nature, and build upon past experiences and standard procedures. This area is rife with opportunities for developing an information technology based intelligent agent for test planning. This system must be internet based such that the users can interact in real time from their remote site in the test planning process. The system that is proposed would deal mainly with the technical aspects of testing and would be, for example, able to aid the test engineer in at least the following areas: balance selection; instrumentation availability, layout, and optimization; sting selection, availability, and optimization; grit location and sizing; model stress analysis; safety criteria and special precautions; run schedule optimization; test safety and readiness reviews; final reporting; work flow planning; staffing requirements and plan; etc. Requirements for developing the data reduction program should also be included in this planning tool, but will be addressed in more detail in a later element.

• Remote access model design and manufacturing system. As shown in Fig. 5, one of the most time consuming activities in a wind tunnel test cycle is design and manufacturing of the wind tunnel model. This process currently takes several months to complete and is usually at a location removed from the testing site. If the goal of conducting a wind tunnel test cycle, including model design and manufacturing in 30 days is to be realized, then revolutionary reductions in the time to manufacture the model will have to be achieved. Essentially, a 9-fold reduction in the time to design and fabricate a wind tunnel model will be required to achieve a 6-fold reduction in the overall time to conduct a wind tunnel test cycle. Model manufacturing times of the order of 2 weeks for a cruise model, or 3 weeks for a high-lift model will be required to meet this goal. There are two different concepts for model fabrication: one wherein the user brings a fabricated model to the test site, and one wherein the model is fabricated at the test site. Maximum potential for using wind tunnel testing as an iterative design tool will arise from manufacturing the model and modifications at the testing site. Very few machine shops will have the capacity to respond to this work load on short notice, but a network of machine shops, connected by the internet could provide the capability to manufacture a model in a very short period, and essentially on demand. The internet in this case would have to be secure, since the detailed coordinates of the configuration are competitively sensitive information. The idea here would be for the customer to send the loft lines to the test site, over the internet. These lines would very quickly be converted to coordinates and specifications for wind tunnel model components. The manufacturing internet would be activated to determine which local shops have numerically controlled milling machines available, and the respective model coordinates would be sent to those shops. The components would be manufactured and delivered to the test site for assembly. Modifications to the model, either during a continuous or high-frequency test , could be machined at the test site, in their own shops, or by the network of local shops.

• Rapid data reduction program development. One of the longer activities in the preparation for a wind tunnel test is the time required to development the data reduction program. To support the 30-day test goal, the data reduction program must be developed and checked out in 2 weeks or less. This will require many changes in our processes. Clear documentation of the capability of the data system must be provided to user, as well as a description and timetable for the material they must provide to the programmers. The time required to develop the program must be decreased through the use of menu driven programming and information technology and troubleshooting tools. In addition, the entire data system, from sensors to computers must be checked out in the model preparation rooms prior to installing the model in the test section. Extensive use of the internet must be made in developing the program to insure communication between the users and the programmers. Special purpose data reduction requirements will always present a problem, and to a first approximation, it should be avoided for tests having very aggressive completion schedules. In the event that special purpose programming is required, modified standard modules must be used as much as possible, and state-of-the-art programming tools must be utilized to reduce the time required to develop the special purpose data reduction programs.

• One day balance calibration capability. As the potential for a large number of short tests increases to meet the requirements of aircraft development programs, the ability to calibrate wind tunnel balances in a very short time is absolutely critical. It will also be critical to have the ability to pull a balance out of a model in the tunnel, perform a quick check calibration on the balance when the data indicate that there is a problem with the balance. This capability will require three things: 1. A dedicated team of experienced people to staff a Balance Calibration Laboratory. , 2. An automated balance calibration machine appropriately sized and sufficiently accurate to meet the requirements., and 3. A fully developed neural net that can be used to both increase the accuracy of the calibration and minimize the amount of data that must be taken to produce a calibration to the required accuracy. This very rapid balance calibration capability is even more important in the environment wherein a series of short, 2 - 3 day tests are occupying the facility. If the data are suspect, the model can be completely removed from the test section, the balance recalibrated, and the model reassembled in time to be ready for the next available testing window.

• Rapid installation - deinstallation of models. The ability to conduct a wind tunnel test cycle in one month is critically dependent upon the ability to install fully assembled and checked out models in two hours. This contrasts to current practice of several days. Rapid model installation is also an enabling capability for the just-in-time testing element wherein the requirement will arise to interrupt a lower priority test inorder to install and run a higher priority test will arise. Rapid installation makes just-in-time testing feasible. Rapid installation is composed of three subelements: 1) Fully equipped model preparation rooms where models can be assembled and once the data system fully is checked out, fully assembled models transported to the test section, 2) Equipment for rapid attachment of a fully assembled model to the primary model support, and 3) Equipment for rapid interfacing of the model instrumentation to the primary data reduction system. Each of these subelements will be discussed seperately due to their importance on the overall testing process:

- Model Preparation Rooms -- Fully equiped and staffed model preparation rooms must be available. Equipment to assemble wind tunnel models on stings or mounting systems that will be installed directly into the test section must be available. Staffing of the rooms will have to accomodate several models of testing. In some cases, site personnel will assemble the model, and in some cases user personnel will asssemble the model. In either situation, the model preparation rooms must be staffed with personnel skilled in model assembly and preparation. Local rapid machining capability will be needed to modify the models at the testing site, or to fabricate new parts for the test matrix. Fully capable data systems must be available in the model preparation rooms to fully check out all of the data gathering instrumentation in the model. It will probably be advantageous for the data system in the model preparation room to also be the primary data system for data acquisition in the test section. This would eliminate potential problems that might arise in switching to a different data system when the model is moved from the model preparation rooms to the test section. Some care will have to exercised to insure that the additional line length does not corrupt the data system, but this does not seem to be an insurmountable problem.

- Rapid Attachment Systems -- Hardware to mount fully assembled models to the primary model support system in the test section will be needed. This hardware will need to be able to support installation times of the order of 30 minutes. Pre-loaded couplings offer an attractive possibility to achieve this goal. In all probability, the widespread use of taper fit joints will not be compatible with rapid installation requirements. The hardware must also incorporate built-in reference systems such that model attitiude in the test section can be readily determined. For models that require utilities, such as electrical power, high pressure air, hydraulics, etc., be provided, maximum use of quick-disconnect couplings must incorporated into the model support hardware.

- Rapid Data System Interfacing -- Equipment must be installed in both the model preparation rooms and the test sections that will support rapid interfacing of the model instrumentation system with the data acquisition system. On-board digization of the data gathered within the model appears to be very promising. Once digitized, the data can be transmitted to the data system using either optical or radio frequency transmitters. The only wires allowed to bridge the metric break must be limited to those required for model utilities or to insure the stability of the primary metric system on the model, such as balance heaters.

• Virtual, interactive control rooms. Virtual, interactive control rooms are the technology that enables the transformation of a normal wind tunnel test into an interactive tool for aircraft design. Aircraft design, by nature, is a multidisciplinary process that involves many groups, which have traditionally worked separately with infrequent communication. The emerging ability to connect diverse groups interactively, and in real time over the internet offers the potential of speeding the aircraft design process. The capability to transmit final wind tunnel data in near real time to multiple sites and connect these sites interactively such that near real time design decisions can be made is critical to achieving the design cycle time reduction goal. The expression has recently been made by Boeing that the sun never sets upon the airplane development process, meaning that portions of the design and manufacturing take place at sites located around the world 24 hours a day. If we were to restrict the discussion to the product definition phase alone, the “new Boeing” could possibly involve groups located at St. Louis, Long Beach, as well as the many sites in the Seattle area. Data from a wind tunnel test would be transmitted to these sites simultaneously and each site would be completely and interactively immersed in the testing process as if they were actually at the test site. Configuration changes suggested by the data would be integrated across all aspects of the design process in near real time, thereby leading to a more rapid convergence upon the final aircraft lines. One of the remote sites would be the primary control room for the user, and this site would have the capability to input a run sequence for the wind tunnel. With automatic control systems, the location of the individual who inputs the conditions to be spanned in a run sequence is immaterial. Protection of the facility from being given unsafe operating conditions is a part of the automatic control system, as well as the local bench board operators. In addition, real time model information must be transmitted to the virtual control room to build confidence in model fidelity of the remote users. This information must include high fidelity video,with hand-held, close-up capabilty to capture model details such as fit of parts, smoothness of surface, condition of transition strips, etc. In addition, some sort of tactile sensor/transmission capability must be provided. This could be in the form of a stylus that would transit contours to a video display, or interconnected gloves that would transmit to the user the smoothness of the model surface as a similar glove is moved across the surface of the mode. The entire virtual control room capability described above appears to be a ideal opportunity for direct and tangible contributions from Information Technology.

•High-speed, near real-time data acquisition systems. The data system must be sufficiently fast that it is not on the critical path to obtaining a data point. The physics of the wind tunnel flow should be the controlling factor in the time to acquire a data point, and the actual time for the data to be acquired must be in the shadow required to change flow conditions or model attitude in the tunnel. Modern, parallel architecture, data reduction systems are capable of meeting this requirement if sufficient attention is given to the details of the entire data acquisition system.

The ability to provide near real-time data is a much more challenging and critical requirement. If data are to be transmitted over the internet to remote virtual control rooms, those data must be final with all corrections included. All corrections, updates, and parameter changes will have to be included. Currently, final wind tunnel data are transmitted to the user after the wind tunnel test is concluded, sometimes with a lag of several months. The revolutionary transformation of traditional wind tunnel testing into a next generation design tool requires that final data be available in near real time since design decisions will be made upon that data as the wind tunnel test proceeds. These design decisions will result in changes in the aircraft configuration, which will lead to the final lines and loads as the design converges. **The capability to acquire final, corrected data in near real time is absolutely critical to the use of wind tunnels as a next generation design tool.**

• Institutionalized, advanced instrumentation and test techniques. Conventional tests utilizing a standard balance for force measurements and electronic scanners of pressure (ESOP) for discrete pressure measurements will easily fit into the paradigm of a 30-day test. Some of the new advanced instrumentation and test techniques must be essentially institutionalized to approach the same level of routine operation as wind tunnel balances and ESOP systems. Advanced instrumentation systems that must be institutionalized are pressure sensitive paint, temperature sensitive paint, global skin friction measurements using either paint or liquid crystals, IR thermography, model deformation, and optical model attitude measurements. Among these, pressure sensitive paint and global skin friction measurements would have by far the largest payoff for the airplane development process. Off-body flow field measurement capability, either qualitative or quantitative, are important, but will not probably see routine use during the testing process. Instead, they will be of value to understand the flow about the aircraft when vortex or wake tracking is important, or when the reasons for a particular design's poor performance must be determined.

One of the primary objectives of advanced wind tunnel testing technology is to provide free air data from wind tunnels. This will require the ability to remove all tunnel induced effects from wind tunnel data. The wind tunnel induces effects upon the data due to the walls, model support tare and interference, non-uniformities of the flow in the test section, unsteadiness of the flow in the tunnel, and turbulence in the tunnel flow. In order for the wind tunnel to be a valid next generation design tool, the ability to correct for all of these effects must be developed and implemented for routine use. Corrections for wall and support system interference, and tunnel flow nonuniformities need to be made in near real time. Corrections for tunnel flow unsteadiness can be made by proper timing and sampling time of the data acquisition system. Corrections for flow turbulence in the wind tunnel are an intrinsic part of the extrapolation of the wind tunnel data to flight Reynolds numbers and must be made as a part of the design cycle, but not necessarily in real time during the conduct of the test. However, these corrections must be made on a time scale consistent with the goal for greatly reduced time for product definition.

• Overall high facility productivity. Herein, productivity will be defined as a measure of the number of data points taken per unit time, such as polars per occupancy hour. Two types of productivity are beginning to emerge, one the “traditional productivity” that we all understand and the second we will call “virtual productivity”. The traditional productivity deals with speeding up every detailed process of the wind tunnel testing process. Achieving high traditional productivity requires speeding up the model installation process, decreasing the time to get on test conditions, decreasing the time to take, reduce, and display the data, decreasing the time to make model changes, decreasing the time to pressurize and depressurize the tunnel, decrease the time for tunnel inspections, decreasing the unplanned down time, and decreasing the time to remove the model from the test section. Achieving high productivity requires developing a detailed model for the testing process, similar to that developed for the NWTC studies. The high payoff areas for improvement must be identified and resources applied to every detail of the testing process. Hardware improvements to the wind tunnels will often be required.

The second type of productivity, “virtual productivity” is emerging from the concept of the application of neural net technology to the testing process. Neural nets offer the promise of reducing the number of actual data points that must be taken to define the aerodynamic characteristics of the configuration. Neural nets are essentially a self learning interpolation scheme. A sufficient amount of data must be taken to educate the net regarding the non linearities of the aerodynamics, and the neural net can provide any amount of interpolated data. The net effect is to increase the actual number of data points that must be taken in the tunnel, thus increasing the productivity. A later element will discuss the data uncertainty requirements, and the neural net capability must be integrated with the data uncertainty requirements to insure that the data meet the requirements of the user.

GENERIC SUSTAINING ELEMENTS --

These elements are important to the wind tunnel testing process in general, and fall into a category of things that are required if the data from a particular wind tunnel is of sufficient quality to be the basis for an aircraft design. They are however not critical to the goal of a 6-fold reduction in the time to conduct a wind tunnel test cycle.

• On-line, near real-time data uncertainty analysis tools. As the performance guarantees of commercial and military aircraft become increasingly precise, the variance of the information used to develop the aircraft becomes correspondingly small. The acceptable variance of wind tunnel data has over time decreased significantly. To insure that the data taken during a wind tunnel test fall within the bounds of acceptable variance, on-line data uncertainty analysis is required. If the data fall within acceptable bounds, then the test should proceed, but if the data fall outside of the bounds, then the test should be halted until the problem can be resolved. The data uncertainty from any wind tunnel test is a combination of the variability of the tunnel flow and the inaccuracy of the data system. Both of these must be monitored continually, but over somewhat different time scales, to ensure that the data are acceptable.

In addition, as we begin to deploy neural nets into tunnel operation and balance calibration, we will have to be confident that the data extracted from the neural net meets all of the data accuracy requirements of the users. The on-line data uncertainty analysis tools and neural net technology must be integrated.

• Thorough, detailed facility calibrations. We must be able to tell users of our facilities what accuracy they can expect from our wind tunnel testing. Thorough, detailed facility calibrations form the basis for establishing the quality of data that can be produced in our facilities. In addition, we must understand the flow in our facilities in order to define potential areas of improvement.

• Flow quality consistent with customer requirements. The requirement for increased accuracy of wind tunnel data has been discussed above as it relates to the aircraft design process. Accurate data cannot be produced in wind tunnels that have poor flow quality. We will need to continually asses the data quality requirements of our customers and modify the facilities to provide flow quality consistent with that data quality. The basis for determining the improvements will be the facility calibrations as well as special studies that must be conducted to increase our knowledge of the facilities. Facility modification projects would then be proposed based upon our understanding of the flow and the result of special studies. For example, it appears to rather straightforward to make modifications to the Ames11-Ft. TWT that would lead to acoustic flow quality in the test section essentially equal to that specified for the National Wind Tunnel Complex. These modifications have been proposed for a FY ‘00 CoF project and would result in the 11-Ft. having the best acoustic flow quality of any transonic wind tunnel in the world. Even so attention will have to be given to insure that other important measures of flow quality meet the requirements of the users.

• Quick-installation calibration models. In order to insure that the flow quality of the facility does not degrade with time, it will be important to periodically perform a spot calibration of the facility. In order to do this in a time consistent with high facility productivity, quick-installation calibration models to determine facility flow quality continuity will be required. For example, both the Ames 12-Ft. and the 11-Ft. have turbulence reduction screens upstream of the test section. These screens will undoubtedly become clogged as the facilites are operated, and some method of easily and quickly determining the continuity of flow quality in the test section must be developed. A standard calibration model, that can be quickly installed in the test section must be obtained, and this model must be kept under strict configuration control to insure that its contours, surface condition and instrumentation remain constant from test to test.

• Customer oriented metric capability and testing processes. The capability, accuracy, and number of sensors in our instrumentation inventory must be adequate to meet the demands of our customers. We must have an inventory of wind tunnel balances that will span the range of loads that will be encountered in the spectrum of tests likely to be conducted. We must have an inventory of pressure sensors that span the ranges and extent likely to be encountered. We must be able to measure model attitude to the accuracy required by our customers, and it is assumed that basic tunnel conditions will always be measured to sufficient accuracy.

We must have standardized test processes that will guarantee both the validity of our test data and the repeatability from test to test. However, we must not be so rigid in adhering to standardized procedures that we cannot respond to special request from a user. If a user has a procedure that produces higher quality data than our procedures, we must be willing and have the capability to quickly modify our procedures.

ADDED VALUE ELEMENTS --

The following elements are not critical to conducting a wind tunnel test in 30 days, but they are critical to the entire process wherein wind tunnel testing becomes a next generation design tool.

• Current-aircraft data bases. One of the criteria in the Boeing study to determine primary and secondary test facilities for their aircraft development programs is "Previous Boeing Database". Most aircraft companies have a design methodology which builds upon previously acquired databases. Design data being acquired for the configuration a company is currently developing is usually referenced back to the data they acquired on the last configuration they developed. It is very important that current aircraft data bases be developed and maintained in the primary development facilties in the country. Once a facility has been modified and returned to operation, it will be important to benchmark the performance of the modified facility against the data obtained to develop previous aircraft.

Development and maintenane of current aircraft data bases is a shared responsibility of the operators and users of the wind tunnels. If the primary development facilites in the country are to mainatained in a state that they can respond to any test request, we all must be aggressive in establishing databases for the most recent aircraft in our tunnels.

• Information systems for aerodynamic knowledge. This and the following element are at the very core of the capability to bring about revolutionary reductions in the time required to define a new aircraft product. The process of converting the data obtained in a wind tunnel to aerodynamic knowledge has, in the past, taken several months. The goal of the TESTING 2000 paradigm is to convert the data to knowledge in essentially near real time during the test, such that when the last data point is taken, the user has gleaned all of the design knowledge he needs from the test, and is ready to proceed to the next desing iteration. This represents an enormous opportunity for the application of Information Technology. The tools that must be developed to help an aerodynamcist, located either in the actual or the virtual control room, draw conclusions from the wind tunnel data will be useful in many other aspects of the aircraft development process, as well as in many other fields wherein a massive amount of data are acquired, and decisions must be made upon those data. If the product definition reduction goal of Boeing and NASA is to be achieved, it is absolutely critical to enable the designers to expand their mental horizons and to think and reach decisions in a fraction of the current time.

• Real-time aircraft design tools. If the ability to conduct a wind tunnel test in 30 days can be realized, then the entire nature of the relationship between CFD and wind tunnel testing changes. For the past two decades, we have been driving toward an assumed goal wherein CFD would replace wind tunnels as a design tool, and the wind tunnel would be essentially used only to verify the final design. However, if we reach the situation that it takes essentially less time to conduct the test than it does to obtain a single CFD solution, then the relationship changes. We now must consider that the role of CFD will be to develop the original configuration, define configuration changes based upon the wind tunnel data, remove tunnel induced effects in the data, and facilitate the extrapolation to flight conditions. If we focus only upon the ability to make essentially real time configuration changes during a test, then a new suite of CFD tools will be necessary. These tools will have to be robust, easy to use, blindingly fast, and calibrated for their accuracy and limitations. This represents another enormous opportunity for Information Technology. These tools may not be first principles CFD calculations, but rather tools to extract and draw conclusions from previously computed CFD solutions. The primary requirement being that they can be used to quantify configuration changes required to meet design goals.

Typical scenarios of the how this and the previous element would work together would be: 1) The data indicate that the performance of a winglet is below the design goal and that the airfoil, size and location of the winglet must be changed to achieve the design goal. A new winglet would be designed essentially concurrently with acquiring the data and understanding what modifications need to be done. The contours would be sent to machine shop at the test site, a new winglet machined over night, and the new winglet tested the next day. or 2) The data indicate that the performance of the wing is falling far below the design goals and that the thickness, location of maximum thickness, and twist must be changed to meet the design goals. The model would be pulled from the tunnel, and a new wing would be designed in about 2 days.

These contours would be sent to local machine shops over the internet and new wings would be machined in about 6 days. These wings would be returned to the testing site, the model assembled and fully checked out. The model would be reinstalled in the tunnel 14 days after it was pulled out, and a test of 2-3 day duration would be completed on the new wing.

• Information Management System. During a wind tunnel test wherein data will be generated at a very fast rate, the amount of data to be assimilated will very large. For example, several different instrumentation systems will be providing data, results of relevant previous tests will be used as benchmarks, and many previously computed CFD solutions will be used to guide data interpretation as well as to guide configuration changes. Some kind of efficient Information Management System will be required. This system could be DARWIN, or a DARWIN like system. It must be institutionalized and accessible in both the actual and virtual control rooms.

The basic ideas and concepts in a new paradigm for wind tunnel testing, TESTING 2000, have been described in the foregoing paragraphs. As the U.S. industry faces the requirement to at least halve the development time for new aircraft in order to remain competitive, the product definition time for new aircraft must also be at least halved. Since wind tunnel testing constitutes a major portion of the product definition process, the time to conduct a wind tunnel test cycle must correspondingly reduced. If, for example, Boeing’s stated goal of halving the time, and cost, of bringing a new aircraft to market is to be realized, the ability to conduct a wind tunnel test cycle in about 30 days, or 1/6th the current time, will be absolutely mandatory. This ability to conduct a wind tunnel test cycle in such a revolutionarily short time span will require that most, if not all of the ideas and concepts set forth in the description of the TESTING 2000 paradigm be developed and implemented in our major developmental, high-productivity, wind tunnels. We may find that more will be required, but TESTING 2000 represents a set of ideas and concepts that will enable, at least major progress toward achieving a 6-fold reduction in the time to conduct a wind tunnel test cycle.