CHALLENGES AND OPPORTUNITIES IN FLUID MECHANICS RESEARCH

Jerry N. Hefner, William L. Sellers III, Dr. James L. Thomas,
Dr. Richard W. Wlezien and Dr. Richard R. Antcliff
NASA Langley Research Center
Hampton, VA 23681-0001

Abstract

The next generation of advanced aircraft systems will not only have performance levels that exceed that of current aircraft, but will also be environmentally compatible and economically viable. Non-conventional aerodynamic concepts as well as efficient, accurate, and useable aerodynamic design and analysis tools will be required to achieve this new standard in aircraft systems and will require major advances in fluid mechanics. This advances will focus on understanding, modeling, and controlling complex viscous three-dimensional flows including the effects of Reynolds number, compressibility and flow unsteadiness. Research in boundary layer transition (including receptivity), turbulence, separated and vortical flows will be required to provide the basis for new aerodynamic technologies .

The paper discusses the fluid mechanics challenges and opportunities that must be addressed to achieve the vision for a new standard in aircraft systems. Areas that are discussed include: experimental fluid mechanics, computational fluid dynamics, viscous flow control, and measurement science.

Introduction

Competitive strength in the global aircraft systems market requires that aircraft manufacturers throughout the world produce aircraft that not only meet performance guarantees and are environmentally compatible, but must also be affordable. This places new emphasis on technologies that reduce both design and manufacturing costs as well as time to market. Additionally, future aircraft systems will be required to provide significant performance improvements at costs comparable to that of current aircraft.

These future aircraft systems obviously will evolve from current design concepts and practices; however, a new generation of aircraft systems can be expected when the technologies are developed that enable aerodynamic, structural, and propulsive efficiencies far beyond those being considered today. The commercial long-haul air transportation systems will not only evolve from conventional wing-body-nacelle-empennage concepts (see Figure 1, taken from Reference 1), but may also incorporate non-conventional or even radical concepts such as blended-wing-bodies, spanloaders, oblique wings, and strut-braced wings (see Figures 2-5 taken from Reference 1). Other concepts for highly nonplanar lifting systems are discussed in References 2 and 3 and include box wings, ring wings, joined wings, and crescent wings. Future commuter aircraft, as well as future military cargo/assault aircraft, can be expected to look and perform very differently than today and will evolve from tiltrotor/tiltwing short take-off and landing concepts. Personal transportation systems, as an option to the automobile, will be developed and integrate the best of helicopter and small aircraft concepts that ensure fail-safe operation and affordability. Military aircraft systems, which have been at the forefront in revolutionary design, will continue to pursue revolutionary design concepts, such as completely integrated aero-propulsion concepts, in the quest for improved range, payload, maneuverability, maintainability, survivability, and affordability.

The potential performance improvements that could be achieved with new non-conventional aircraft concepts are very impressive. Consider, for example, the next generation of large subsonic transports. Figure 6 (from Reference 1) provides a comparison of a next generation conventional subsonic transport with a non-conventional transport configuration (i.e., blended wing-body). Note that the blended-wing-body (BWB) has a reduced TOGW and increased L/D. An even larger blended-wing-body subsonic transport (800 passenger) with laminar flow and constructed completely from composite materials would have over a 50% increase in L/D compared with an advanced conventional subsonic transport; 38% if the conventional transport had laminar flow (see Figure 7, taken from Reference 1). With a range of 7000 nautical miles, this non-conventional transport concept is projected to have a fare or ticket price that is between 19-26 % less than the comparable conventional subsonic transport. These associated performance gains with non-conventional aircraft concepts will require aggressive technology developments beyond the state of the art in all disciplines of aeronautics including aerodynamics, structures and materials, flight controls, avionics, and propulsion, and will also require the technology developments in the various disciplines to be highly integrated in a multidisciplinary manner.

High aspect ratio wings with thick airfoil sections; high aspect ratio, strut-braced wings with thin airfoil sections; laminar flow wings, fuselage, empennage and nacelles; high lift wings without slats and/or flaps; and integrated aero-propulsion systems may be typical of the aerodynamic concepts that will be important to the development of the next generation of advanced aircraft systems. However, these aerodynamic concepts will require the fluid mechanics phenomena associated with large-scale flow separation, vortical flows, complex juncture flows, viscous wakes, aerodynamic and propulsive flow interference/interaction, laminar flow, transition, relaminarization, turbulence, and shock/boundary layer interactions to be better understood, predicted and controlled. Thus, major advances in computational and experimental design and analysis tools, flow control, and aero-propulsion configuration concepts will depend on this enhanced understanding of the viscous flow phenomena and Reynolds number effects associated with complex 3-D compressible flows about realistic aircraft configurations. These computational and experimental aerodynamic design and analysis tools will also have to be much more accurate, affordable, reliable, and useful than those that the aircraft designer uses today since there will be a paucity of practical flight performance databases and experience for the non-conventional aerodynamic concepts. Passive and active flow control concepts will be critical for drag reduction, increased lift, vortical and separated flow control, and aerodynamic noise reduction. These flow control concepts will have to be integrated with structures, flight controls, and propulsion concepts to provide the foundation for the development of innovative aerodynamic configuration concepts that completely integrate the propulsion system within the airframe to significantly enhance not only aerodynamic and propulsion efficiencies, but also structural efficiency.

The purpose of this paper is to highlight some of the more important challenges and opportunities in fluid mechanics research that will arise in the development of computational and experimental design and analysis tools and flow control concepts for the next generation of commercial and military aircraft. The paper will address: (1) experimental fluid mechanics including the enhanced understanding of critical flow physics, (2) computational fluid dynamics, (3) viscous flow control, and (4) advanced measurement science.

Experimental Fluid Mechanics

In the early 1980's there was initial optimism that CFD would replace experimental fluid mechanics research. In the 1990's, that optimism has been replaced by the knowledge that both computational and experimental fluid mechanics must work more closely together. Today, experimental fluid mechanics research is paced by measurement technology and ground/flight testing capability and CFD research is paced by computer power, algorithm development, and turbulence modeling. Future advances in CFD will place an even greater demand on experimental fluid mechanics research to provide accurate and highly-detailed data in extremely complex flows. This future research will be directed toward uncovering the complex flow physics issues and providing databases for flow model development.

Experimental fluid mechanics is facing exciting new challenges. These challenges are due to the increased knowledge required to obtain improved performance and competitiveness of both conventional and non-conventional aerodynamic configurations. Even in the realm of conventional aerodynamics, there are areas where conventional design technology has been pushed so far that "plateaus" have been reached. High-lift system design and noise reduction represent typical examples.

The design and optimization of a high lift system is a complex task. There have been several excellent reviews that describe extensive programs to improve high lift system design (References 4 and 5). High lift systems involve most of the complex, pacing issues in fluid mechanics. (see figure 8) These include boundary layer transition, relaminarization, viscous wake interactions, flow separation and shock/boundary layer interactions. Meredith (Reference 6) describes the viscous phenomena affecting high lift systems. Flap and slat gap and overhang must be balanced to optimize the often conflicting requirements for either C_{Lmax} or C_L at approach conditions. Pushing the high lift system design too far can result in flow separation and serious degradation in performance. The experimental research in high lift aerodynamics is being directed in two paths; (1) database development for improved turbulence modeling and computational prediction capability; and (2) active control technology to sense and eliminate separation if it occurs.

Improved turbulence modeling and prediction capabilities require a better understanding of the flow physics associated with high lift systems, and a hierarchy of improved models and prediction methods must be developed. The sensitivity of a modern high lift system with Reynolds number has been well documented. Future experimental work will focus much of the effort in the high Reynolds number regime to improve our understanding of these sensitivities. This understanding is imperative to the development of accurate and reliable wind tunnel to flight scaling criteria. The existing database is inadequate both in terms of the relevance of the experiment and the types of data obtained (Reference 6). Development and validation of the advanced turbulence models will require flowfield measurements of the turbulence properties (Reynolds stresses, anisotropies, dissipation rates, etc.) in boundary layers, separated flows, and complex wakes. Improved prediction methods and models for boundary layer transition and relaminarization will require complex measurements of boundary layer instabilities together with their associated disturbance growth rates, frequencies, wave angles, and receptivity to external sources. All of this will be complicated by the necessity to make the required measurements in thin, high Reynolds boundary layers and in tunnel environments that include high pressures and cryogenic flow conditions. Testing will ultimately evolve to three-dimensional configurations, but in the near future, experiments need to focus less on providing answers to the critical flow physics issues. (Reference 6).

Experimental fluid mechanics will also face challenges in supporting the goals of reduced interior cabin and airframe noise. The turbulent boundary layer on the fuselage has been identified as a dominate excitation force of the fuselage structure (Reference 7). Flight experiments have further confirmed the importance of the turbulent boundary layer pressure fluctuations on the noise in the aircraft cabin. Improved models for the turbulent wall-pressure are critical to reaching the reduced noise levels. The experimental measurement of the turbulent wall-pressure fluctuations will require development of new measurement and test techniques that will allow the mapping of a global, fluctuating pressure field in a thin boundary layer, both temporally and spatially. Since no reliable database exists, numerical simulations at low Reynolds numbers are currently very useful (Reference 7), but verification of any new models for high Reynolds number applications will require experimental verification.

We are approaching an era where the engines may no longer be the dominate noise source during landing conditions. As the engines become quieter, airframe generated noise may become the dominant source. Recent investigations have indicated that vortices generated by the high lift system may be a major contributor to airframe generated noise. Improved experimental databases are required that provide a better understanding of the vortex/structure interaction process and noise source identification; improved turbulence and acoustic models; and validated numerical simulations. Unsteady flowfield measurements and experimental techniques coupling fluid mechanics and acoustics will need to be developed.

The advanced configurations described earlier highlight more opportunities for experimental research. To optimize a strut-braced configuration, like that described in References 8 and 9 and shown in Figure 5, will require a much better understanding of the fundamental flow physics, including those associated with the laminarization of juncture flows. The lower sweep, thinner airfoil, small chord wings utilized by strut-braced configurations make the boundary layer transition and laminar flow control issues simpler, but the contamination of a laminar flow by a turbulent juncture flow is not well understood. There has been considerable research into juncture flows where there are turbulent boundary layers on the body as well as the wing; there is, however, an inadequate database for the case of a turbulent boundary layer from a body propagating into a laminar wing boundary layer of a wing from a juncture flow. Additionally, experimental research is required to identify the critical issues and allow development of improved turbulence models. It is complicated by the task of simultaneously requiring turbulence and transition (stability) measurements. This leads to complete different, and sometimes conflicting, sets of experimental tools required.

The blended wing body (BWB) configuration is receiving considerable attention because of the potential improvements over conventional next generation configurations (References 1 and 10). The BWB configuration is feasible as evidenced by the pioneering Northrop flying wing, B2 and AVRO Vulcan bombers. The new twist involves the use of much thicker airfoils than used before. The designs currently under investigation make use of Goldschmied (Reference 11) airfoil designs. The airfoils approach thickness ratios of 30% to provide static-pressure thrust to counteract drag. This thrust is dependent on boundary layer control to prevent flow separation from the highly cambered upper rear surface of the airfoil.

There are significant fluid physics issues involved with these BWB configurations. Improved understanding of flow separation physics, and boundary layer control will be required to optimize and refine these shapes. Most if not all of the configurations, require the use of hybrid laminar flow control (HLFC) to achieve their design goals (Reference 12). The airfoils have relatively blunt leading edges and the prediction of attachment-line contamination and transition is critical. Several of the advanced concepts have highly integrated propulsion systems and will have to accommodate boundary layer ingestion in the inlet ducts. The management and control of the boundary layer is essential to obtaining the performance goals. The BWB concept does offer the significant advantage of requiring a less powerful high-lift system for takeoff and landing.

There is however, a possible need for slotted cruise airfoils and that will require a much greater understanding of the viscous interactions of wakes and slot and airfoil aerodynamics at high Reynolds and Mach numbers.

Computational Fluid Dynamics

Computational Fluid Dynamics (CFD) complements both theory and experiment in the design, development, and assessment of the next generation of aircraft . The simulations from CFD codes provide pathfinder demonstrations of new technology and an improved understanding of flow phenomena for fundamental investigations in fluid mechanics. In many cases, CFD has been used to design new experimental facilities.

A schematic representation of the advances made in CFD over the past 25 years is shown in Figure 9 and discussed in depth in Reference 13. The push of technology, including advances in computers and algorithms, is upward and to the right, as indicated by the arrow in the figure. The dates shown represent times at which new capabilities were introduced. For complex configurations, solvers for nonlinear inviscid (potential and Euler) equations were available at the end of the '70's, and Reynolds-Averaged Navier-Stokes (RANS) solvers were available at the end of the '80's. The times shown represent capability for general classes of geometries and are only approximate; as an example, the 1990 date for RANS calculations was chosen because five papers describing applications of RANS solvers for complex configurations appeared in the AIAA Journal of Aircraft that year. The far right column denotes direct simulations of transitional and turbulent flows accomplished through full unsteady solutions to the Navier-Stokes equations. These methods are yet in their infancy since applications are currently possible only for simple geometries and low Reynolds numbers; however, their use is becoming more important in establishing databases that can be used to assess and create more accurate turbulence models for use in large-scale computations.

Much progress has been made over the past 25 years (see Reference 13) such that RANS algorithms are being used extensively in the aircraft industry today, because of improvements three areas: computer speed, computational algorithms, and turbulence models. The challenge is to further extend this capability to complex configurations with reduced variation and faster turnaround. Parallel processing and distributed workstation computing hold promise for attaining increased computational speed and memory. Industry, particularly McDonnell Douglas and Pratt and Whitney, is relying upon distributed workstation computing for production computing capability.

In terms of algorithms, a substantial potential for acceleration of convergence to steady state exists with current solvers. The best multigrid codes require on the order of 1500 fine-grid residual evaluations for convergence to engineering accuracy, independent of the number of mesh points. Realizing the optimal convergence rates that are attainable for elliptic equations for the RANS equations is a formidable challenge but would reduce the number of required floating point operations by two orders of magnitude. This efficiency improvement would open up avenues for time-dependent and design applications that are beyond the reach of today's computers. Higher-order algorithms and adaptive -grid algorithms represent alternate methods to reduce the computational requirement for a specified level of accuracy, but remain largely unexploited for large scale computations. The labor-intensive part of the computation must be reduced as well through automated grid generation techniques, including both structured- and unstructured-grid methods, for viscous simulations.

Transition and turbulence modeling (particularly for 3-D, separated, vortical, and compressible flows) is the major barrier to large-scale computations with RANS codes in the sense that uncertainties due to the numerical discretization errors are becoming less than the uncertainties attributable to turbulence modeling. Boundary layer transition computations will not only be required to accurately predict the beginning of transition, but will also have to model the complete transition process to enable the assessment of Reynolds number scaling from ground test to flight Reynolds numbers. Combined computational, theoretical, and experimental research is needed to improve the steady and unsteady flow turbulence models for industrial flow application since direct numerical simulation of turbulent flows, even with the large-eddy scale approximation, is limited to relatively low Reynolds numbers and currently requires large computing resources.

A critical need in CFD is to make the systems more useable as a block box by the designer, who will input a specified level of accuracy in both the numerical and the physical model, and be returned the result within the limitations of a specified computational cost and turnaround time. Thus, future CFD codes can be expected to have a hierarchy of turbulence models with the appropriate physics corresponding to the aircraft designer's requirements for particular applications..

Viscous Flow Control

The control of viscous flows for airframe performance improvement is at first glance a highly innovative concept, but has been practiced in one form or another over the history of aircraft design. One might argue that the camber control used in the Wright Flyer was an early form of viscous flow control, in which attached flow was maintained to higher lift levels by actively warping the wing. Vortex generators, pressure gradient shaping, and programmed devices such as slats and flaps are commonplace on modern transport aircraft.

The limitation on applying flow control to aircraft aerodynamics is not the range of flow phenomena that can be influenced. Physical concepts already exist for flow separation control, viscous drag reduction, control of shock boundary interactions, three-dimensional separated flows, noise-generating shear flows, and transition to turbulence. The present limitation exists in the devices that can be used to effectively influence viscous flows for net performance improvement.

Innovative new airframe concepts such as the blended wing body will need innovative new approaches to drag reduction, noise reduction, and flow separation control. The aerodynamic equivalent of integrated electronics is required for quantum advances to occur in aircraft performance and economics. Highly reliable integrated systems which are capable of passively or actively modify shear flows, which autonomously activate in flight regimes and airframe locations when they are needed, and which revert to passive states with no adverse performance penalty are the target of much present day flow control research.

The first requirement for developing advanced flow control concepts is the development of a detailed understanding of the underlying flow physics. Prime examples of flow control developed based on the physical understanding of complex flows is suction for boundary-layer transition delay and riblets for drag reduction in turbulent boundary layers (see Reference 14). The application of active suction to laminar boundary layers requires detailed understanding of the stability characteristics of laminar boundary layers. By drawing a small fraction of the boundary layer flow through sufficiently small surface holes, the stability characteristics of the boundary layer can be modified to the extent that transition to turbulence is postponed, with an accompanying reduction in viscous drag. Contrary to popular misconception, the boundary layer is not removed; instead the shape of the boundary layer profile is slightly changed. In the case of riblets, the underlying near-wall structure of the turbulent boundary layer is modified by streamwise grooves in a way to interfere with drag producing events in the boundary layer. From a simplistic perspective one might not expect increased surface roughness to reduce drag. The overly simplistic approach in which the underlying physics of the flow is not considered has led to ill-fated attempts such as Teflon coating the surface in an attempt to skin friction.

As noted earlier, passive flow control has found its way onto conventional aircraft in many forms. Vortex generators are commonly used for separation and lift control, and often appear when problems arise in the management of viscous flows. Rows of small devices adorn the wings of modern transport aircraft, and recent advances in developing sizing relationships (Reference 15) have optimized the impact of these devices relative to any accompanying performance penalties. Passive mixers are utilized in high bypass engines to reduce the bulk velocity of the jet stream and the accompanying jet noise components. These lobed mixers are sufficiently large so that their influence is primarily inviscid in nature. Mixing is augmented simply by creating an increased shear-layer cross section. The negative aspect of passive devices is that a performance penalty can occur in flow regimes for which the devices are not directly required. The vortex generator that is designed to control separation when high lift devices are deployed translates into a drag producing device in cruise.

In an attempt to alleviate some of the penalties associated with fixed passive devices there has been much recent interest in flow control devices that can be actuated based on flow regime. Nozzles with deployable ejectors can be used to promote mixing and noise reduction for takeoff and landing, with the hardware being stowed for cruise. On a smaller scale, individual vortex generators have been actuated in the laboratory using smart materials such as shape memory alloys (SMA) to deploy and retract devices on demand (see Reference 16). An SMA stores deformation energy at ambient temperature that can be released by heating the device. If an aerodynamic element can be made to deploy using aerodynamic forces, an SMA can be electrically heated to provide a restoring force to stow the device. The concept provides the opportunity to cover wings with arrays of smart vortex generators, which can be deployed and retracted on demand.

At the next level of complexity exist the most exciting opportunities for viscous flow modification. In this case, actuators actively intervene with the dynamics of a flow event. While this is yet a more complex form of viscous flow control, it also provides the greatest long-term opportunity. Models have already been developed for transition control through active suppression of boundary layer disturbances, noise suppression by active suppression of cavity resonances, and mixing enhancement by active enhancement of shear-layer instability modes. By choosing the appropriate ways to interact with the flow, there is an opportunity for substantial net payback to be achieved.

To date many experiments in active flow control have been executed at low Reynolds number where they exploit the characteristics of laminar instabilities to achieve large changes in the overall flow characteristics. The instability of laminar free shear layers has been particularly exploited, for example for flow separation control or the modification of jet noise sources. In most cases these methods have been limited to low Reynolds number applications. The loss of spatial organization in the flow structure at elevated Reynolds number has been the death knell for a variety of techniques, such as the ill-fated attempts to organize high Reynolds number hot jet flows by acoustic excitation. Any practical application of flow control must necessarily cross the Reynolds number barrier.

Actuation is generally acknowledged to be the prime limitation of active control strategies. In general one must be capable of applying moderate forces over large areas with large displacements at elevated frequencies. Furthermore the interaction between an actuator and the flowfield of interest is nonlinear and highly three-dimensional. Typical approaches involve blowing, suction, or moving surfaces. In the case of the first two, a lumped system approach using pumps and ducting have made this technology impractical. Moving surfaces, on the other hand, can be locally actuated using magnetostrictive, piezoelectric, electrostatic, or thermally driven devices. Micro electromechanical devices (MEMS) have recently showed promise because of the ease of massive replication, but their efficacy at high Reynolds numbers remains unproved (see Reference 17).

Sensing of the flowfield and the effect of actuation on flow characteristics is the second major element of active flow control. Sensing must be distributed over the region of interest and must be capable of measuring the appropriate flow parameters. Smart sensor systems, which make qualitative judgments such as the degree to which a flow is separated, are a necessary element of an active system. New sensing technologies that employ MEMS, fiber optics, and integrated computing at a reasonable cost and level of reliability are a necessary precursor to the implementation of active technologies.

The third element of the flow control triad is the control algorithms that link actuation to sensor systems. Due to the distributed nature of sensing and actuation, the control systems must be likewise distributed rather than centrally located. Approaches to control theory that integrate models of the fluid dynamic response to actuation have recently shown promise. Distributed approaches that rely on integrated neural networks and genetic algorithms show promise for these applications.

System integration is a key element of any practical flow control system. Recent advances in multifunctional structures have demonstrated that highly integrated electronic, sensing, and structural systems can increase system reliability while simultaneously lowering cost. Integration of actuation, sensing, and control electronics into composite structures may ultimately be the path by which flow control systems become a useful part of next-generation airframes.

System robustness is paramount for any active flow control system to make its way onto production aircraft systems. Maintenance, reliability, and reparability are first order issues for airframe applications. An active system must be able to degrade and fail gracefully. This is particularly true for distributed systems, where massive replication can compensate for the loss of individual flow control elements.

Advanced Measurement Science

Measurement technology has always been an integral part of fluid mechanics and aerodynamics testing in both ground and flight facilities. The measurement systems are the eyes and ears of the experimental researcher and new insights and understanding regarding critical fluid mechanics phenomena will be highly dependent upon the capability and integrity of these systems. Thus, advancements in aerodynamics leading to the next generation of aircraft systems will necessitate the development of both evolutionary and revolutionary fluid mechanics measurement systems. These future measurement systems must be able to obtain increasing amounts of data faster while at the same time maintaining or advancing measurement accuracy. These systems will require the capability to obtain data in "quiet" environments without disturbing the highly controlled flow. The measurement systems will obtain data over large expanses rapidly, or even instantaneously, to directly impact the design/test cycle time. They will obtain data in harsh and unstable conditions to try to understand these complex systems. The measurement system may even be integrated into the aero structure.

While these challenges are daunting, there are significant reasons for optimism about the potential of future measurement systems technologies. Although these technologies are still in their early years of development, limited applications of current knowledge have already shown what needs further understanding and what needs improvements in accuracy and reliability. It is expected that these technologies will bear fruit soon and impact aerodynamic research. However, there are some technologies that are only a glimmer in some scientist's eye. These concepts and ideas have the potential of redefining our understanding of aerodynamical systems. Theoretical and early experimental laboratory studies have brought to light phenomena which could not have been seen in the past because of the inherent limitations of the measurement systems. These revolutionary concepts will be required to enable aerodynamics to leapfrog forward past current limiting physical understandings. The following are a small sample of measurement systems, in both the adolescent and embryonic stages that will be necessary for researchers and designers to reduce design/test cycle time and achieve significant aerodynamic performance improvements.

The first of these areas relates to the process that is required to repeatedly design, test and eventually qualify an aerodynamic system. One of the inherent limitations of this process is the immense amount of data which must be obtained to validate the applicability and accuracy of the computational analysis and design tools as well as the performance of the aero system or concept. Obtaining this data is both expensive and time consuming. The thrust of the research effort in this area is to conceive measurement systems which will obtain the required information in a fraction of the normal time and at reduced costs.

One such system which has received considerable attention is pressure sensitive paint (PSP) (see Reference 18). This measurement system has the ability to produce pressure information across the surface of an aerodynamic structure, essentially instantaneously. The technology is based on the interaction of air (actually oxygen) molecules with chemicals embedded in a "paint" applied to the model surface. These systems have the potential of replacing pressure transducers and tubing which is normally used to collect pressure data in aerodynamic and fluid mechanics experiments. This would produce significant cost savings in the production of instrumented wind tunnel models and flight test articles. This technology is currently being investigated, to some degree, by all of the major aircraft manufacturers.

Another important measurement technology is Doppler global velocimetry (DGV) (see Reference 19). This measurement system has the ability to obtain instantaneous three dimensional velocity information in a flowfield plane. The technology is based on the Doppler shifting of laser light scattered from sub-micron fluid tracers. This system will allow the aerodynamic designer to obtain fluid flow information quickly to validate his designs and computational models. Measurements which may have taken days to perform can be completed in minutes with this system. Systems are currently being investigated at NASA, the US Air Force, the DLR and others.

A whole new field of planar measurements depend upon the interaction of lasers with molecules in the flowfield (see Reference 20). Several variants of this technology include laser-induced fluorescence, Rayleigh scattering and four wave mixing spectroscopy. These techniques do not depend upon physical tracers in the flowfield, but rather interrogate the molecules directly to determine velocity, temperature, density and perhaps pressure. Much of the research in this area is embryonic but some significant individual applications have been accomplished.

In the area of measurements to validate performance improvements, data to assess and understand the physics of the aerodynamic/acoustic environment will be critical. The ability to understand and shape this environment will lead to significant performance improvements. The thrust of the measurement science in this arena has been in investigating technologies which provide new methods and ability to probe the underlying physics. The requirements for measurement accuracy and resolution are particularly severe in this area. There are several new technologies which show particular promise.

The first of these new technologies is acoustic arrays (see Reference 21). This measurement technology area allows the researcher to pinpoint the source of aircraft noise. This is obviously critical to the reduction of aircraft-generated noise. This measurement area is currently being investigated to determine whether the fundamental technology can be extended to "hard-walled" facilities; this extension will allow this critical measurement to be made in the large majority of wind tunnels currently in operation, without the need for extensive acoustic treatment.

"Smart surface" velocimetry is another potentially important measurement science area . This velocimetry system would utilize a holographic-based laser velocimetry system to acquire velocity measurements very close to the model wall. If the challenge of seeding the flow can be overcome, this technology presents the potential of obtaining these critical measurements within the boundary layer. This may, for the first time, provide the dynamic transition and turbulence data necessary to develop and validate the transition and turbulence models needed in future computational analysis and design tools.

Another area which may have significant long term impact is micro-electro-mechanical systems (MEMs). This measurement science area uses silicon chip technology to formulate mechanical measurement systems. These devices are being investigated as embedded sensors for shear, pressure and other aerodynamic quantities. Important technical challenges need to be overcome before these device can be uses in practical systems.

Concluding Remarks

Aeronautics beyond the year 2000 will be both challenging and exciting. A new generation of aircraft systems can be expected with performance that far exceeds that of today's best aircraft. These aircraft systems will be both environmentally compatible and economically viable in a highly competitive global market. These future aircraft systems will depend on major advances in aerodynamics, structures and materials, and propulsion. In the area of aerodynamics, major challenges and opportunities in fluid mechanics research exist that must be addressed. Advancements are required in experimental fluid mechanics, computational fluid dynamics, flow control, and measurement science. Major thrusts are required in understanding, predicting, and controlling high Reynolds number viscous flows with emphasis on transition and turbulence in compressible, three-dimensional, unsteady, separated flows. Fluid mechanics research will be expected to provide both experimental and computational aerodynamic design and analysis that will enable aerodynamic designers to reduce both design time and costs while achieving results with the desired levels of accuracy. Advancements in measurement science and technology are essential to obtain the required detailed flow physics data for developing and validating new computational flow models and viscous flow control techniques. Control of flow separation, receptivity and transition, turbulence, and vortical flows will be essential to the development of radical new aircraft systems employing blended-wing-body concepts, spanloaders, oblique wings, strut-braced wings, box wings, ring wings, etc.

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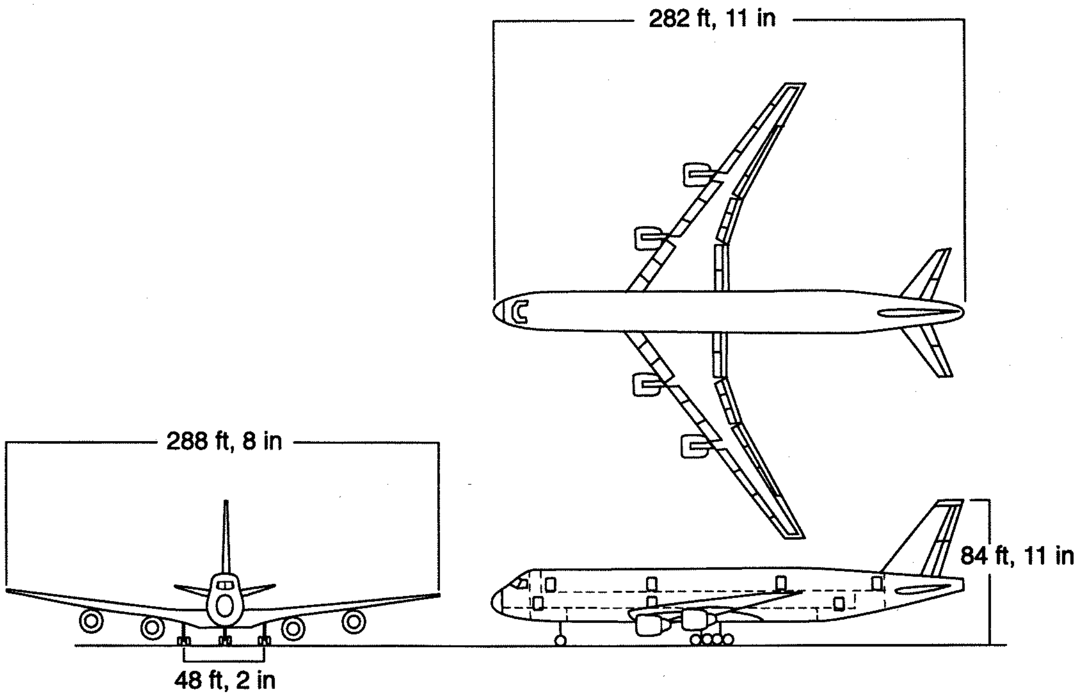

FIGURE 1 - A Conceptual 800-Passenger Conventional Aircraft (Reference 1)

Range	= 7,100 nm	800 passengers mixed class
TOGW	= 800,000 lbs	4 - 60,000 lb class ADP's (fan reversing)
Wing Area	= 10,000 ft2	Initial cruise altitude 35,000 - 45,000 ft
Wingspan	= 320 ft	Composite non-cylindrical pressure vessel

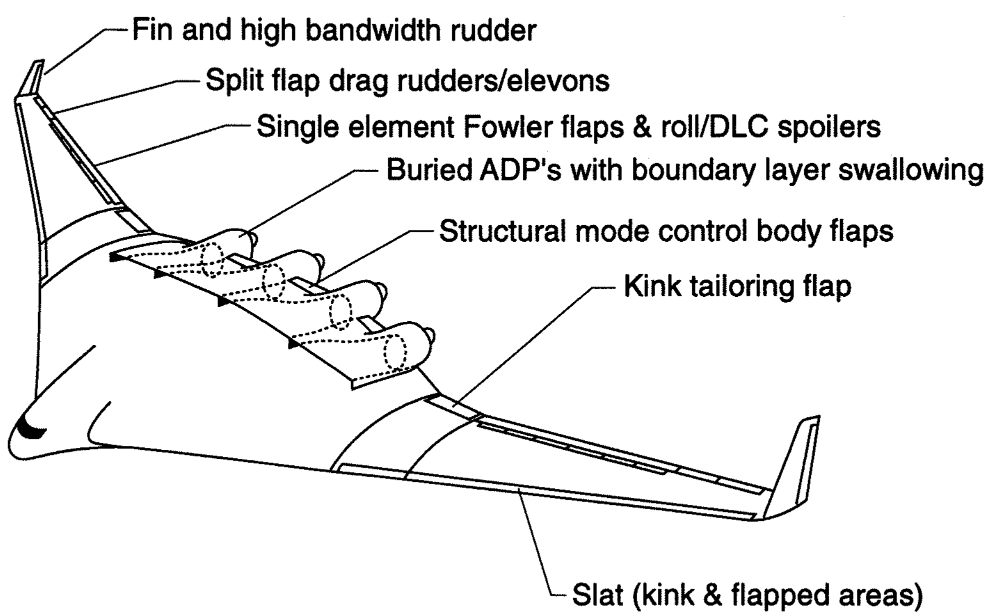

FIGURE 2 - The Characteristics of the 800-Passenger Blended Wing Body (Reference 1)

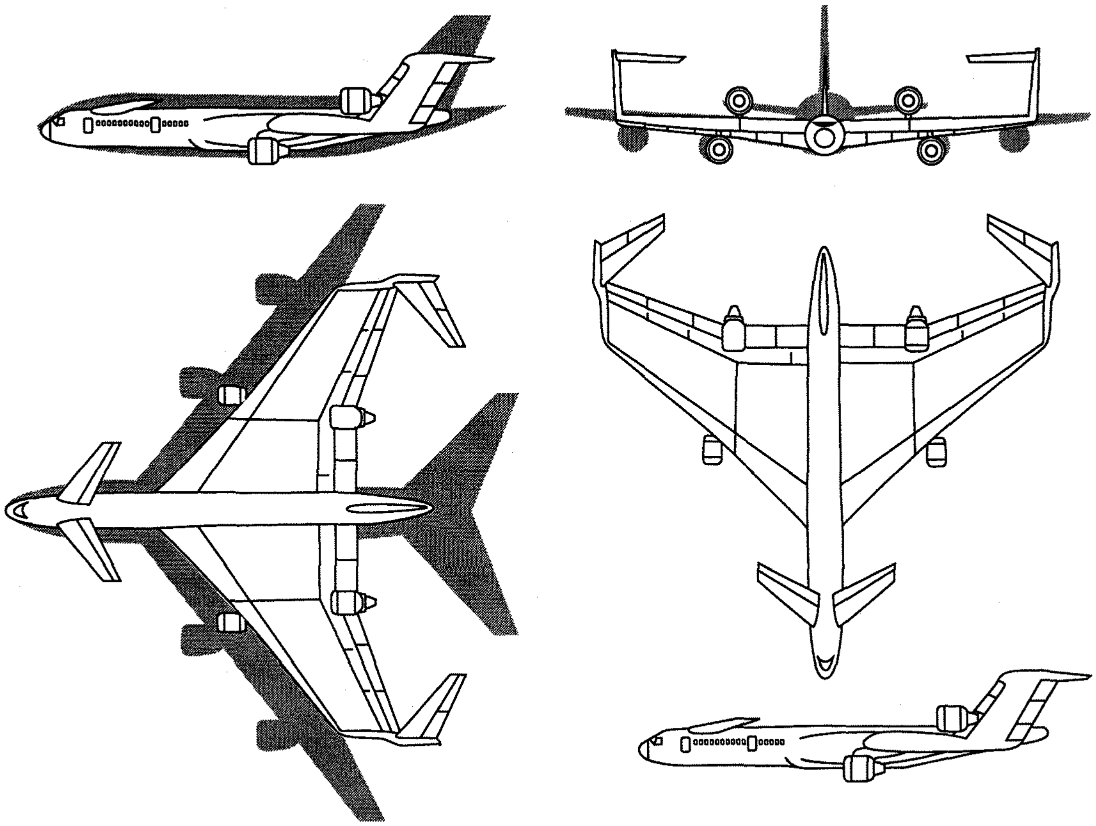

FIGURE 3 - A Conventional Configuration and a More Radical Configuration (Reference 1)

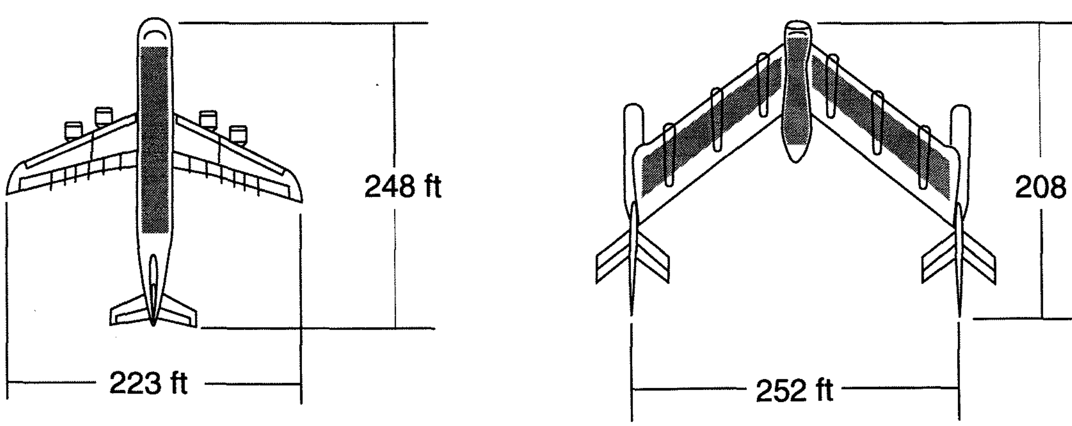

FIGURE 4 - A Comparison between Conventional Heavy Lifter and Spanloader Concept (Reference 1)

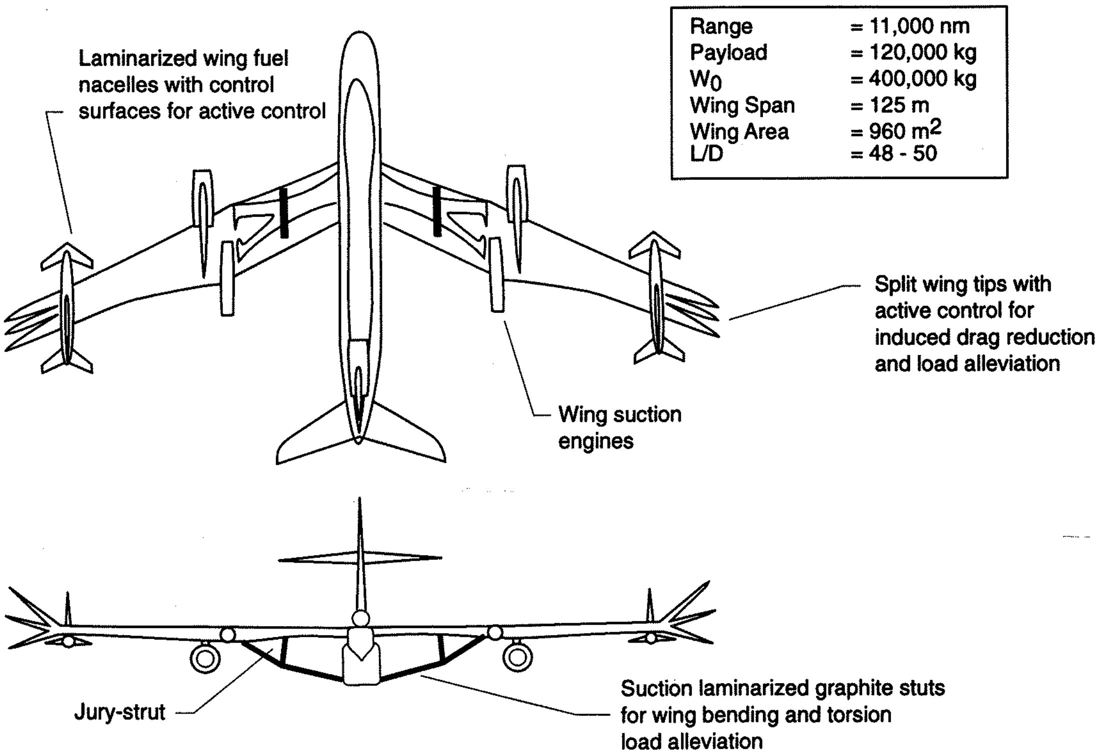

FIGURE 5 - Strut Braced Wing Concept (Reference 8)

Synergistic Technology Transport (STT)		Blended Wing-Body (BWB)
8,500	Design range, nm	8,500
368	Passengers (3 class)	368
0.85	Cruise Mach	0.85
VHBR (3)	Engines	VHBR (2)
30.6	Thrust, klb	30.9
188	Wing span, ft	260
236	Length, ft	167
2,020	Wing area, ft^2	4,500
17.5	Aspect ratio	15.0
367,200	TOGW, lb	338,800
192,700	OEW, lb	195,300
23.1	L/D	33.3
-68%	Fuel burn/seat at 3,000 nm	-25.7%

FIGURE 6 - Comparison of the Synergistic Technology Transport (STT) and the Blended Wing Body (BWB) Configurations (Reference 1)

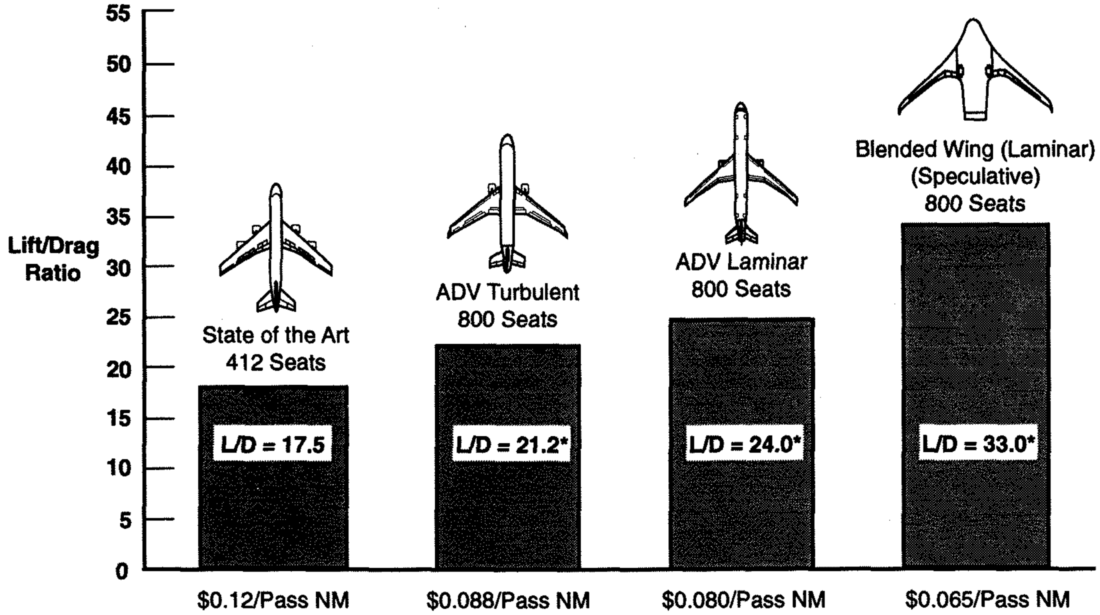

FIGURE 7 - Summary of the Potential Improvements in Subsonic Lift-To-Drag Ratio (Reference 1)

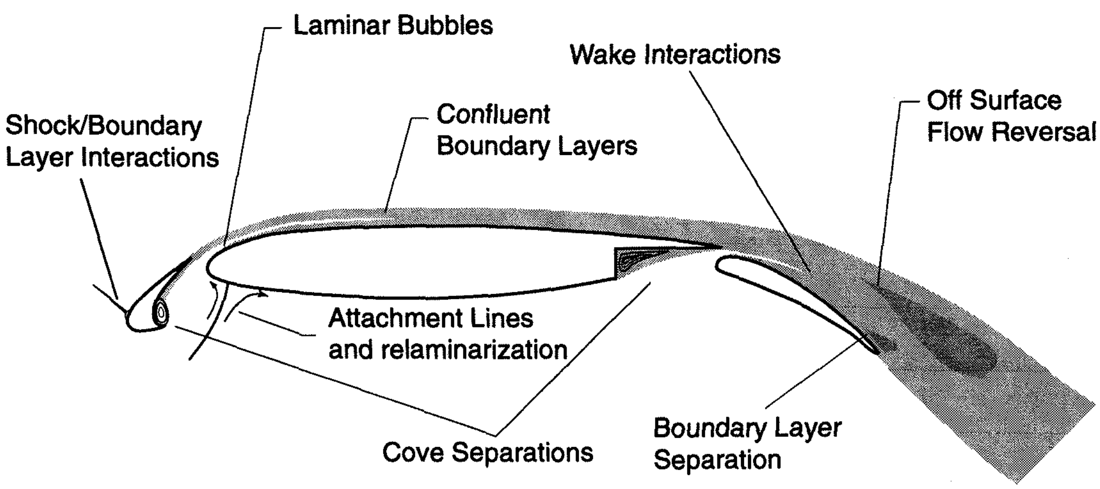

FIGURE 8 - Flow Features of A High-Lift System

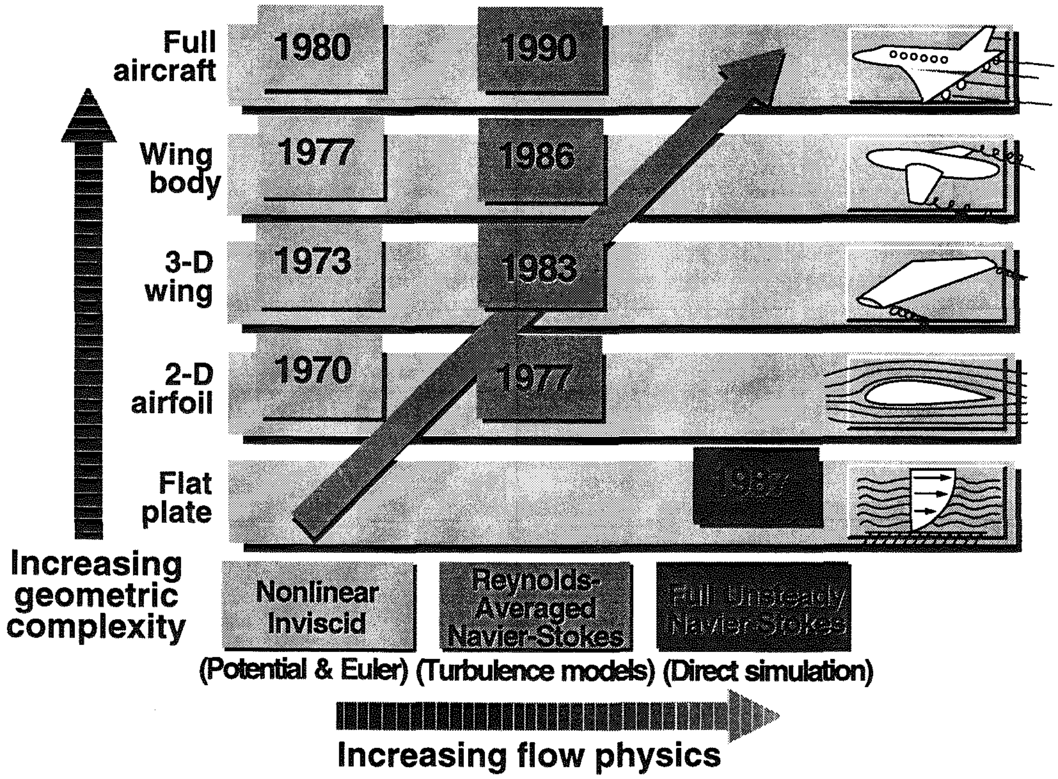

FIGURE 9 - The evolution of CFD