NASA Conference Publication 10184
Part 2

Transportation Beyond 2000: Technologies Needed for Engineering Design

Proceedings of a workshop sponsored by the
National Aeronautics and Space Administration
and held at Langley Research Center,
Hampton, Virginia
September 26–28, 1995

February 1996

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Transportation Beyond 2000: Technologies Needed for Engineering Design

Compiled by
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Langley Research Center • Hampton, Virginia

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About the Logo

The logo depicts the broad range of transportation discussed at the workshop, including the first revolutionary transportation innovation, the wheel, and the winged vehicle from the NASA logo orbiting the earth. The question mark at the center of the logo depicts the mystery of the transportation concepts that will be available to us and future generations.

Workshop Video Information

The entire workshop was videotaped for archival purposes and is available for loan or duplication. For viewing or checkout, contact the NASA Langley Library at Mail Stop 185. For duplication, contact the Video Production Group at Mail Stop 425A.

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Foreword

One of the defining characteristics of humankind is the simultaneous blessing and curse of considering the future. As we currently understand the situation, other animals dwell exclusively in the present (except for some instinctive activities). In the current post-cold-war scenario of global "economic warfare" and in a world where other nations plan long term, the U.S. must actively work longer term technology requirements and capability projections in the economic arena to the same or greater extent to what was so successfully done in the military arena during the Cold War.

This workshop constitutes a contribution toward such planning in the transportation sector of the economy. The results of this workshop indicate that virtual revolutions in physical transportation are required by society and will be enabled by technology either in the research pipeline or envisaged as being within the "Frontiers of the Responsibly Imaginable."

Dennis M. Bushnell
Langley Senior Scientist
Workshop Sponsor

Preface

The "Transportation Beyond 2000: Technologies Needed for Engineering Design" workshop was held at the NASA Langley Research Center during September 26-28, 1995, under the sponsorship of the Langley Aerodynamics Technical Committee and the Langley Senior Scientist. The purpose of the workshop was to acquaint the staff of the NASA Langley Research Center with the broad spectrum of transportation challenges and concepts foreseen within the next 20 years. The hope is the that material presented at the workshop and contained in this document will stimulate innovative high-payoff research directed toward the efficiency of future transportation systems.

This workshop was a bit unusual in that it consisted entirely of invited presentations of advanced transportation concepts and technologies in the context of future needs for the total transportation system. Insofar as possible, the speakers were from outside Langley.

The workshop included five sessions designed to stress the changing environmental, social, and technological factors that will lead to a revolution in the way we will travel in the 21st century. This revolution will encompass land, air, and space vehicles and will include non-conventional electronic virtual travel. The first session provided the historical background and a general perspective for future transportation, including emerging transportation alternatives such as working at a distance. Personal travel was the subject of Session Two. The third session looked at mass transportation, including advanced rail vehicles, advanced commuter aircraft, and advanced transport aircraft. The fourth session addressed some of the technologies required for the above revolutionary transportation systems to evolve. The workshop concluded with a wrap-up panel discussion, Session Five.

The topics presented herein all have viable technical components and are at a stage in their development that, with sufficient engineering research, one or more of these could make a significant impact on transportation and our social structure.

As previously noted, the goal of the Transportation Beyond 2000 Workshop was to stimulate NASA Langley's research community and encourage them to apply their expertise to innovative high-payoff transportation research. Over 200 Langley personnel attended the 2.5-day workshop, and most attendees spoke positively of the program and speakers. Most participants indeed felt quite inspired by the topics discussed. As in all meetings, the organizers learn afterwards that some key element of the workshop subject was inadvertently overlooked. This advanced transportation workshop was no exception, and the topics of water transportation and high-speed light rail were two that were pointed out by participants. The otherwise favorable comments and overall high level of interest illustrate the need for NASA Langley to pursue transportation systems research, as well as a need to get the workshop information out to as many researchers as possible.

Now that the workshop itself is over, there is the need to keep alive the ideas presented in order that the purpose of the meeting may not be lost. To emphasize this point, consider the following comment from the panel discussion at the end of the workshop:

> ". . . I think there is one flaw in the NASA program at this point, and that is in the commuter area. We pat ourselves on the back on the positive balance of trade, but in the 30 to 100 seat commuter there is a negative one billion dollar balance of trade in this country. We are losing a billion dollar market and we don't have a single company in that market. None! We gave it up. NASA did a good study in 1982 on that subject, the Stack report. We sometimes do a very good job of saying what we should do and then we don't follow through. So we gave up that billion dollars, so let's not do it in the other areas as well. Let's listen to what we are saying, and let's go do it." (Steve Justice, Lockheed-Martin, 9/28/95.)

To this end, three actions have been undertaken. The first is this conference publication of the workshop proceedings. The second is the placement of the video recordings of the presentations and the panel discussion taken during the workshop in the NASA Langley Research Center's Learning Center where they are available for loan and/or viewing. The third is to stimulate transportation-related breakthroughs from within Langley's research community.

Langley Aerodynamics Technical Committee

Acknowledgments

The preparation for a workshop intended for the entire staff of the Langley Research Center involved much coordination and assistance from personnel outside the Langley Aeronautics Technical Committee. A number of individuals were instrumental in the success of the workshop, and they are cited below for their efforts:

Thomas Brinkley	Proceedings Publications Guidance
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Susan Walters	Workshop Agenda Viewgraphs Generation
Cathy Watson	Public Affairs Coordination
Patricia E. J. Williams	*LaRC This Week* Editor

Finally, without the support and encouragement from the Langley Senior Scientist, Mr. Dennis M. Bushnell, this workshop would surely not have taken place and been as successful as it turned out to be.

Workshop Program

September 26, 1995

8:30-8:45 ***Welcoming Remarks***, Roy V. Harris, Jr., NASA Langley Research Center Assistant Director for Research and Engineering

8:45-9:00 ***Opening Remarks/Introduction of LATC Members***, William J. Small, LATC Chairman

Session 1: Historical Background and General Future Perspective.
Chairman: Dr. John E. Lamar

9:00-10:00 ***The History of Transportation, With a Peek Into the Future***, Dr. John D. Anderson, Jr., University of Maryland

10:00-10:15 **BREAK**

10:15-11:15 ***In Search of Cybernautics***, Prof. Steven C. Crow, University of Arizona

11:15-12:15 ***The New Organization: Rethinking Work in the Age of Virtuosity***, Duncan B. Sutherland, The Sutherland Group, Inc.

12:15-1:15 **LUNCH**

Session 2: Personal Travel.
Chairman: Scott C. Asbury

1:15-1:45 ***The Future of Transportation in Society: Forces of Change***, Dr. Barbara C. Richardson, Transportation Research Institute, University of Michigan

1:45-2:15 ***The Smart Highway Project: Smart Highways, Smart Vehicles, Smart Engineering***, Ray D. Pethtel, Virginia Polytechnic Institute and State University

2:15-3:00 ***Hypercars: The Next Industrial Revolution***, Dr. Amory B. Lovins, Rocky Mountain Institute

3:00-3:15 **BREAK**

3:15-3:45 ***Flying Cars***, Prof. Steven C. Crow, University of Arizona

Session 3: Mass Transportation.
Chairman: Abel O. Torres

3:45-4:15 ***Aerodynamics of MAGLEV Trains***, Dr. Joseph A. Schetz and Dr. James F. Marchman III, Virginia Polytechnic Institute and State University

4:15-4:45 ***Magnetic Levitation Systems for Future Aeronautics and Space Research and Missions***, Dr. Isaiah M. Blankson and John C. Mankins, NASA Headquarters

September 27, 1995

Session 3: Mass Transportation (Continued).
Chairman: Robert E. McKinley

8:15-8:45 ***Far Term Visions in Aeronautics***, Dennis M. Bushnell, NASA Langley Research Center

8:45-9:15 ***History, A Projection of the Future: A Rotary Wing Perspective***, Robert J. Huston, Distinguished Research Associate, NASA Langley Research Center

9:15-9:45 ***Highly Nonplanar Lifting Systems***, Dr. Ilan Kroo, Stanford University

9:45-10:15 ***The Application of Pneumatic Lift and Control Surface Technology to Advanced Transport Aircraft***, Robert J. Englar, Georgia Tech Research Institute

10:15-10:30 **BREAK**

10:30-11:00 ***The Future of Very Large Air Transport Vehicles: A Lockheed Martin Perspective***, R. Steven Justice, Anthony P. Hays, and Ed L. Parrott, Lockheed Martin Aeronautical Systems

11:00-11:30 ***Evolution of the Revolutionary Blended-Wing-Body Subsonic Transport***, Dr. Robert H. Liebeck, Mark A. Page, and Blaine K. Rawdon, McDonnell Douglas Aerospace

11:30-12:00 ***Large Capacity Oblique All-Wing Transport Aircraft***, Thomas L. Galloway, James Phillips, NASA Ames Research Center, Mark Waters, Eloret Institute, and Robert Kennelly, Jr., NASA Ames Research Center

12:00-12:30 ***A Corporate Supersonic Transport (CST)***, Randall Greene, Aeronautical Systems Corp., and Dr. Richard Seebass, University of Colorado

Session 4: Advanced Technologies for Future Transportation Concepts.
Chairman: Robert C. Scott

1:30-2:00 ***Integrated Airframe Technology: The Future of Advanced Composites***, David F. Taggart, Lockheed Martin Skunk Works

2:00-2:30 ***Fuel Cells for Transportation: Status and Technical/ Economic Needs***, Glenn Rambach, Lawrence Livermore National Laboratory

2:30-3:00 ***Hypersonic Airbreathing Vehicles/Technologies***, James L. Hunt, NASA Langley Research Center

3:00-3:15 **BREAK**

3:15-3:45 ***The Use of Steady and Pulsed Detonations in Propulsion Systems***, Dr. Henry G. Adelman, Thermosciences Institute, Gene P. Menees, NASA Ames Research Center (retired), Dr. Jean-Luc Cambier, Thermosciences Institute, and Jeffrey V. Bowles, NASA-Ames Research Center

3:45-4:15 ***A Pre-Mixed Shock-Induced-Combustion Approach to Inlet and Combustor Design for Hypersonic Applications***, John P. Weidner, NASA Langley Research Center

September 28, 1995

Session 4: Advanced Technologies for Future Transportation Concepts (Continued).
Chairman: Lawrence D. Huebner

8:15-8:45 ***Energy Beam Highways Through the Skies***, Dr. Leik N. Myrabo, Rensselaer Polytechnic Institute

8:45-9:15 ***High Energy Density Matter for Rocket Propulsion***, Dr. Patrick G. Carrick, Phillips Laboratory, Edwards AFB

9:15-9:45 ***Fusion Power and Propulsion for Future Flight***, H. David Froning, Jr., Flight Unlimited

9:45-10:15 ***Advanced Space Propulsion***, Dr. Robert H. Frisbee, Jet Propulsion Laboratory

10:15-10:30 **BREAK**

Session 5: Wrap-Up Panel Discussion.
Moderator: William J. Small

10:30-12:00 Participants:
Dr. John D. Anderson, Jr.
Dennis M. Bushnell
Prof. Steven C. Crow
George Finelli
H. David Froning
Dr. Ilan Kroo
Dr. Robert H. Liebeck

12:00 **ADJOURN**

Presentation Abstracts

The History of Transportation, With a Peek Into the Future, Dr. John D. Anderson, Jr., University of Maryland

In the first part of this presentation, a general historical review of the heydays of various modes of transportation will be given, where "heydays" will be interpreted as periods of fundamental technological development. With this as background, focus will then be placed on the airplane -- the mode of transportation that has changed the world in the 20th century, and which in the minds of many has been the most important technological development in this century. The technical history of air transportation (the airplane) will be reviewed, with special emphasis on the aerodynamic evolution of the airplane. Some specific examples of pivotal technical advances (and breakthroughs) from the history of applied aerodynamics will be discussed. Finally, this historical perspective will be used to help us peek into the future of transportation in the 21st century.

In Search of Cybernautics, Prof. Steven C. Crow, University of Arizona

This is a talk about the future of aviation in the information age.

Ages come and go. Certainly the atomic age came and went, but the information age looks different. Microprocessor speeds have increased by a multiple of 25,000 since their introduction a quarter century ago, a rate of 50% each year, with no sign of slowing. The personal computer on my desk can process data about as fast as my eyes, maybe almost as fast as my brain, but my computer is nearly blind and deaf and has a random access memory span of only 0.07 seconds.

My computer can fly an airplane though. The data rate to process twelve state variables and four controls is 2.56 Kbps (kilo bits per second), and the bandwidth to monitor all variables of 100 airplanes in the neighborhood is 16 KHz, about the same as presently used for voice communications. The Global Positioning System with various enhancements can provide all of the state variables.

The talk reviews some recent experiments on navigation and control with the Global Positioning System. Vertical position accuracies within 1 foot have been demonstrated in the most recent experiments, and research emphases have shifted to issues of integrity, continuity, and availability. Inertial navigation systems (INS) contribute much to the reliability of GPS-based autoland systems. The GPS data stream can cease, and INS can still complete a precision landing from an altitude of 200 feet.

The future of aviation looks like automatic airplanes communicating among each other to schedule ground assets and to avoid collisions and wake hazards. The business of the FAA will be to assure integrity of global navigation systems, to develop and maintain the software rules of the air, and to provide expert pilots to handle emergencies from the ground via radio control.

The future of aviation is democratic and lends itself to personal airplanes. Some data analyses reveal that personal airplanes are just as efficient as large turbofan transports and just as fast over distances up to 1,000 miles, thanks to the decelerative influence of the hub and spoke system. Maybe by the year 2020, the airplane will rank with the automobile and computer as an agent of personal freedom.

The New Organization: Rethinking Work in the Age of Virtuosity, Duncan B. Sutherland, The Sutherland Group, Inc.

Like two enormous steam engines, throttles wide-open, bells clanging and whistles screeching, careening toward each other down the same track, two powerful forces are about to collide and the point of collision will be smack in the middle of the white-collar workplace. Moreover, once the dust has settled, it is quite likely that we will never be able to think about the white-collar workplace in quite the same way again.

The forces couldn't be more different. One force, the theory of complex adaptive systems, has its roots in the radical new sciences of chaos and complexity. The other force, the notion of organizations being learning systems, more like living organisms than "information factories," is an outgrowth of the new management thinking of leading organizational theorists like the Claremont Graduate School's Peter Drucker, MIT's Peter Senge, and Hitotsubashi University's Ikujiro Nonaka. Nevertheless, both the new science and the new management thinking seem to point to a similar and perhaps even startling conclusion: the business organization of the 21st century will look nothing like the bureaucratic organizational model that prevails in most companies today, a model that has remained largely unchanged since the manufacturing heydays of 1950s.

While the details of the new organization remain sketchy, its rough outline is already beginning to take shape. Rather than simply being flatter through the elimination of layer upon layer of "middle management," the new organization is likely to be made up of networks of specialists who will be, for all practical purposes, self-managing. Rather than focusing on issues like re-engineering business processes, a holdover from Taylorism, the focus will be on supporting the continuous learning of an organization's specialists, the sharing of this learning with other specialists, and the embedding of this learning in the organization's physical structure. Finally, rather than viewing themselves as going through relatively long periods of stability punctuated by shorts bursts of "reorganization," business enterprises will come to realize that their very survival depends upon their being in a state of continuous organization.

The implications of the new organization with respect to how companies approach the planning, design, and management of the technology infrastructure that enables individual learning, self-management, and continuous organization, are both numerous and far-reaching. As part of this technology infrastructure, the white-collar workplace exists in the form it does today as a direct result of management's beliefs about how time, space, and tools ought to be organized and managed in order to accomplish useful intellectual work. Obviously, if these beliefs change radically, as both the new science and the new management thinking suggest is about to happen, then it is almost inevitable that the form and function of the white-collar workplace will change radically, as well. Will there even be a white-collar workplace in the 21st century, in the sense of purpose-built facilities designed to support the co-location of large numbers of white-collar workers? Only time will tell. However, the leading indicators seem to suggest that, as the old saying goes, "We ain't seen nothin' yet!"

The Future of Transportation in Society: Forces of Change, Dr. Barbara C. Richardson, Transportation Research Institute, University of Michigan

The transportation system is a critical element of the social/political/economic system of the United States. Factors influencing the use of transportation technology include technology push, market pull, and external factors. In order for new transportation technology to be successful, it must meet the needs of the market. These needs are diverse and vary almost by individual.

Historical trends show great changes in transportation use by mode and origins and destinations of trips. Other important changes in society affecting transportation use include changes in the composition of society by gender, age, national origin, family composition, land use, income, and residential distribution. Changes of these factors in the future and how technology is deployed to meet the changing needs of society will affect the success of transportation technology implementation over the next twenty years.

The Smart Highway Project: Smart Highways, Smart Vehicles, Smart Engineering, Ray D. Pethtel, Virginia Tech

The Smart Highway project is a six mile, limited access roadway being built between Interstate 81 and Blacksburg, Virginia. The initial construction segment will be two miles long and is designed to serve as a test bed and test track for Intelligent Transportation Systems (ITS) research. The Center for Transportation Research (CTR) at Virginia Tech is developing three evaluation tools for its ITS research including DYNAVIMTS (a software framework), and the FLASH Lab (a 1/15th scale model highway and vehicle system). The Smart Highway rounds out the Center's evaluation methodology by allowing full scale operational tests, evaluations, and research under both experimental and conventional traffic conditions.

Currently under development is a concept for a fully automated highway using a

"Cooperative Infrastructure Managed System" which involves ultra wide band communication beacons installed in the infrastructure with appropriate sensors, receivers and processors on board the vehicles. The project is part of the research program funded by the National Automated Highway System Consortium. The CTR hopes to develop the automated concept to prototype status by 1997. Other smart transportation and smart engineering concepts are proposed.

This presentation will address the goals and objectives of the Smart Highway project, overview its status and importance to the region, and identify some of the transportation technology now under development and planned in the future.

Hypercars: The Next Industrial Revolution, Dr. Amory B. Lovins, Rocky Mountain Institute

The auto industry--one-seventh of the GNP, and the highest expression of the Iron Age--is about to trigger the biggest transformation in industrial structure since the microchip. Ultralight cars molded from net-shape advanced composites can be severalfold lighter than present steel cars, yet safer, sportier, and more comfortable, durable, and beautiful. Modern hybrid-electric drives boost efficiency ~1.3-1.5x in heavy steel cars, but ~ 5-20x in ultralight, very slippery platforms. Synergistically combined into ultralight-hybrid "hypercars," these elements can yield state-of-the-shelf family cars that average 150-300+ mi/gal--twice that with state-of-the-art technologies--yet can also be superior in all other respects, probably including cost: carbon-fiber monocoques can actually be cheaper to mass-produce that steel unibodies.

Designing cars more like aircraft and less like tanks requires not only a ~400-500 kg curb mass and very low air and road drag, but also an aerospace philosophy of engineering integration. Mass, cost, and complexity turn out to compound with heavy hybrids but to decompound with ultralight hybrids, owing partly to radical simplification. Excellent aerodynamics, preferable including advanced techniques for passive boundary-layer control, will be the key to successful design integration.

Transforming automaking is a competitive and environmental imperative, could form the nucleus of a green industrial Renaissance, and would enhance national security by, among other things, saving as much oil as OPEC now extracts. However, this transformation faces serious cultural barriers. For example, hypercars will be more like computers with wheels than like cars with chips--they'll have an order of magnitude more code than today's cars--but Detroit is not a software culture. Just the transition from stamped and welded steel to integrated and adhesive-joined synthetics is difficult enough.

Nonetheless, hypercars are rapidly heading to market in the late 1990s, because ~25 current and intending automakers are eager to capture their potentially decisive competitive advantages--including order-of-magnitude reductions in product cycle time, tooling cost, assembly effort, and parts count. Hypercars will succeed, and may well sweep the market, not because of mandates or subsidies, but because of manufacturers' quest for competitive advantage and customers' desire for better, smarter cars.

Flying Cars, Prof. Steven C. Crow, University of Arizona

Flying cars have nearly mythical appeal to nonpilots, a group that includes almost the whole human race. The appeal resides in the perceived utility of flying cars, vehicles that offer portal-to-portal transportation, yet break the bonds of road and traffic and travel freely through the sky at the drivers will. Part of the appeal is an assumption that flying cars can be as easy to fly as to drive.

Flying cars have been part of the dream of aviation since the dawn of powered flight. Glenn Curtiss built, displayed, and maybe even flew a flying car in 1917, the Curtiss Autoplane. Many roadable airplanes were built in the 1930's, like the Waterman Arrowbile and the Fulton Airphibian. Two flying cars came close to production in the early 1950's. Ted Hall built a series of flying cars culminating in the Convaircar, sponsored by Consolidated Vultee, General Motors, and Hertz. Molt Taylor built and certified his Aerocar, and Ford came close to producing them. Three Aerocars are still flyable, two in museums in Seattle and Oshkosh, and the third owned and flown by Ed Sweeny.

Flying cars do have problems, which so far have prevented commercial success. An obvious problem is complexity of the vehicle, the infrastructure, or both. Another is the difficulty of matching low power for normal driving with high power in flight. An automobile uses only about 20 hp at traffic speeds, while a personal airplane needs about 160 hp at speeds typical of flight. Many automobile engines can deliver 160 hp, but not for very long.

A more subtle issue involves the drag of automobiles and airplanes. A good personal airplane can fly 30 miles per gallon of fuel at 200 mph. A good sports car would need 660 hp at the same speed and would travel only 3 miles per gallon. The difference is drag area, about 4.5 sq ft for the automobile and 1.4 sq ft for the airplane. A flying car better have the drag area of the airplane, not the car!

Aerodynamics of MAGLEV Trains, Dr. Joseph A. Schetz and Dr. James F. Marchman III, Virginia Tech

High-speed (500 kph) trains using magnetic forces for levitation, propulsion and control offer many advantages for the nation and a good opportunity for the aerospace community to apply "high tech" methods to the domestic sector. One area of many that will need advanced research is the aerodynamics of such MAGLEV vehicles. There are important issues with regard to wind tunnel testing and the application of CFD to these devices.

This talk will deal with the aerodynamic design of MAGLEV vehicles with emphasis on wind tunnel testing. The moving track facility designed and constructed in the 6 ft. Stability Wind Tunnel at Virginia Tech will be described. Test results for a variety of MAGLEV vehicle configurations will be presented.

The last topic to be discussed is a Multi-disciplinary Design approach that is being applied to MAGLEV vehicle configuration design including aerodynamics, structures, manufacturability and life-cycle cost.

Magnetic Levitation Systems for Future Aeronautics and Space Research and Missions, Dr. Isaiah M. Blankson and John C. Mankins, NASA Headquarters

The objectives, advantages, and research needs for several applications of superconducting magnetic levitation to aerodynamics research, testing, and space-launch are discussed. Applications include very large-scale magnetic balance and suspension systems for high alpha testing, support interference-free testing of slender hypersonic propulsion/airframe integrated vehicles, and hypersonic maglev. Current practice and concepts are outlined as part of a unified effort in high magnetic fields R&D within NASA. Recent advances in the design and construction of the proposed ground-based Holloman test track (rocket sled) that uses magnetic levitation are presented. It is projected that ground speeds of up to Mach 8 to 11 at sea-level are possible with such a system. This capability may enable supersonic combustor tests as well as ramjet-to-scramjet transition simulation to be performed in clean air. Finally a novel space launch concept (Maglifter) which uses magnetic levitation and propulsion for a re-usable "first stage" and rocket or air-breathing combined-cycle propulsion for its second stage is discussed in detail. Performance of this concept is compared with conventional advanced launch systems and a preliminary concept for a subscale system demonstration is presented.

Far Term Visions in Aeronautics, Dennis M. Bushnell, NASA Langley Research Center

Lecture discusses envisaged advanced concepts across the speed range including VTOL converticars (personal air transportation), advanced subsonic and supersonic long haul transports, hypersonic transports, and developments/applications of flow control technology. In most cases, these concepts and approaches offer at least the potential of 100 percent improvements in various performance metrics and, in some cases, far more. Special emphasis is given to advanced CTOL configurations which may offer simultaneous opportunities for mitigation of both drag-due-to-lift and wake vortex hazard and to synergistic propulsive and aerodynamic interactions.

Lecture concludes that a virtual revolution in the civilian aeronautical world is conceivable as a result of technology maturation in several areas which could enable the exploitation of "end-point" designs.

History, A Projection of the Future: A Rotary Wing Perspective, Robert J. Huston, DRA, NASA Langley Research Center

The success and failure of past vehicle concepts is reviewed in an attempt to highlight some critical issues for future aircraft development. It is the contention of the author that many of the advanced vehicle concepts attempted in the past failed because of a lack of appreciation, by both the sponsors and the developer, for the technical and societal requirements critical to their success. This paper will review the history of some attempts to provide both good hover and forward flight efficiency and will point out some of the technical and societal obstacles encountered. Two examples, that of the tiltrotor and tiltwing vehicles, will be highlighted to show the different paths followed by a successful and an unsuccessful concept. The outlook for future VTOL/rotary wing concepts will be evaluated.

Highly Nonplanar Lifting Systems, Dr. Ilan Kroo, Stanford University

This paper deals with nonplanar wing concepts -- their advantages and possible applications in a variety of aircraft designs. A brief review and assessment of several concepts from winglets to ring wings is followed by a more detailed look at two recent ideas: exploiting nonplanar wakes to reduce induced drag, and applying a "C-wing" design to large commercial transports. Results suggest that potential efficiency gains may be significant, while several non-aerodynamic characteristics are particularly interesting.

The Application of Pneumatic Lift and Control Surface Technology to Advanced Transport Aircraft, Robert J. Englar, Georgia Tech Research Institute

The application of pneumatic (blown) aerodynamic technology to both the lifting and the control surfaces of advanced transport aircraft can provide revolutionary changes in the performance and operation of these vehicles, ranging in speed regime from Advanced Subsonic Transports to the High Speed Civil Transport, and beyond. This technology, much of it based on the Circulation Control Wing blown concepts, can provide aerodynamic force augmentations of 80 to 100 (i.e., return of 80-100 pounds of force per pound of input momentum from the blowing jet). This can be achieved without use of external mechanical surfaces. Clever application of this technology can provide no-moving-part lifting surfaces (wings/tails) integrated into the control system to greatly simplify aircraft designs while improving their aerodynamic performance. Lift/drag ratio may be pneumatically tailored to fit the current phase of the flight, and takeoff/landing performance can be greatly improved by reducing ground roll distances and liftoff/touchdown speeds. Alternatively, great increases in liftoff weights and payloads are possible, as are great reductions in wing and tail planform size, resulting in optimized cruise wing designs. Furthermore, lift generation independent of angle of attack provides much promise for increased safety of flight in the severe updrafts/downdrafts of microbursts and windshears, which is further augmented by the ability to sustain flight at greatly reduced airspeeds. Load-tailored blown wings can also reduce tip vorticity during high-lift operations and the resulting vortex wake hazards near terminal areas. Reduced noise may also be possible as these jets can be made to operate at low pressures.

The planned presentation will support the above statements through discussions of recent experimental and numerical (CFD) research and development of these advanced blown aerodynamic surfaces, portions of which have been conducted for NASA. Also to be presented will be predicted performance of advanced transports resulting from these devices. Suggestions will be presented for additional innovative high-payoff research leading to further confirmation of these concepts and their application to advanced efficient commercial transport aircraft.

The Future of Very Large Air Transport Vehicles: A Lockheed Martin Perspective, R. Steven Justice, Anthony P. Hays, and Ed L. Parrott, Lockheed Martin Aeronautical Systems

The Very Large Subsonic Transport (VLST) is a multi-use commercial passenger, commercial cargo, and military airlifter roughly 50% larger than the current Lockheed C-5 and Boeing 747. Due to the large size and cost of the VLST, it is unlikely that the commercial market can support more than one aircraft production line, while declining defense budgets will not support a dedicated military VLST. A successful VLST must therefore meet airline requirements for more passenger and cargo capacity on congested routes into slot-limited airports and also provide a cost effective heavy airlift capacity to support the overseas deployment of US military forces.

A successful VLST must satisfy three key missions:

- o Commercial passenger service with nominal seating capacity at a minimum of 650 passengers with a range capability of 7,000 to 10,000 miles.
- o Commercial air cargo service for containerized cargo to support global manufacturing of high value added products, 'just-in-time' parts delivery, and the general globalization of trade.
- o Military airlift with adequate capacity to load current weapon systems, with minimal break-down, over global ranges (7,000 to 10,000 miles) required to reach the operational theater without need of overseas bases and midair refueling.

The development of the VLST poses some technical issues specific to large aircraft, but also key technologies applicable to a wide range of subsonic transport aircraft. Key issues and technologies unique to the VLST include: large composite structures; dynamic control of a large, flexible structure; aircraft noise requirements for aircraft over 850,000 pounds; and increased aircraft separation due to increased wake vortex generation.

Other issues, while not unique to the VLST, will critically impact the ability to build an efficient and affordable aircraft include: active control systems; Fly-By-Light/Power-By-Wire (FBL/PBW); high lift systems; flight deck associate systems; laminar flow; emergency egress; and modular design.

The VLST will encounter severe restrictions on weight, ground flotation, span, length, and door height to operate at current airports/bases, gates, and cargo loading systems. One option under consideration is for a sea-based VLST, either a conventional seaplane or Wing-In-Ground effect (WIG) vehicle, which would allow greater operational flexibility, while introducing other design challenges such as water impact loads and salt-water corrosion. Lockheed Martin is currently developing a floatplane version of the C-130 Hercules which will provide experience with a modern sea-based aircraft.

In addition to its own ongoing research activities, Lockheed Martin is also participating in the NASA Advanced Subsonic Technology, High Speed Research (HSR), and other programs which address some of the technologies needed for the VLST. The VLST will require NASA and US aerospace companies to work together to develop new capabilities and technologies for make the VLST a viable part of transportation beyond 2000.

Evolution of the Revolutionary Blended-Wing-Body Subsonic Transport, Dr. Robert H. Liebeck, Mark A. Page, and Blaine K. Rawdon, McDonnell Douglas Aerospace

The Blended-Wing-Body (BWB) airplane concept represents a potential revolution in subsonic transport efficiency for Very Large Airplanes (VLA's). NASA is sponsoring an advanced concept study to demonstrate feasibility and begin development of this new class of airplane. In this study, 800 passenger BWB and conventional configuration airplanes have been compared for a 7000 nautical mile design range, where both airplanes are based on technology keyed to 2015 entry into service. The BWB has been found to be superior to the conventional configuration in the following areas: Fuel Burn--31% lower, Takeoff Weight--13% lower, Operating Empty Weight--10% lower, Total Thrust--16% lower, and Lift/Drag--35% higher.

The BWB advantage results from a double deck cabin that extends spanwise providing structural and aerodynamic overlap with the wing. This reduces the total wetted area of the airplane and allows a high aspect ratio to be achieved, since the deep and stiff centerbody provides efficient structural wingspan. Further synergy is realized through buried engines that ingest the wing's boundary layer, and thus reduce effective ram drag. Relaxed static stability allows optimal span loading, and an outboard leading-edge slat is the only high-lift system required.

Large Capacity Oblique All-Wing Transport Aircraft, Thomas L. Galloway, James Phillips, NASA Ames Research Center; Mark Waters, Eloret Institute; and Robert Kennelly, Jr., NASA Ames Research Center

Dr. R. T. Jones first developed the theory for oblique wing aircraft in 1952, and in subsequent years numerous analytical and experimental projects conducted at NASA Ames and elsewhere have established that the Jones' oblique wing theory is correct. Until the late 1980's all proposed oblique wing configurations were wing/body aircraft with the wing mounted on a pivot. With the emerging requirement for commercial transports with very large payloads, 450-800 passengers, Jones proposed a supersonic oblique flying wing in 1988. For such an aircraft all payload, fuel, and systems are carried within the wing, and the wing is designed with a variable sweep to maintain a fixed subsonic normal Mach number. Engines and vertical tails are mounted on pivots supported from the primary structure of the wing. The oblique flying wing transport has come to be known as the Oblique All-Wing (OAW) transport.

This presentation gives the highlights of the OAW project that was to study the total concept of the OAW as a commercial transport.

A Corporate Supersonic Transport (CST), Randall Greene, Aeronautical Systems Corporation and Dr. Richard Seebass, University of Colorado

This talk address the market and technology for a corporate supersonic transport. It describes a candidate configuration. There seems to be a sufficient market for such an aircraft, even if restricted to supersonic operation over water. The candidate configuration's sonic boom overpressure may be small enough to allow overland operation as well.

Integrated Airframe Technology: The Future of Advanced Composites, David F. Taggart, Lockheed Martin Skunk Works

Advanced composite materials have provided the aerospace community with unprecedented opportunities for design freedom and improved structural performance. While the performance attributes of composites are increasingly being challenged to meet future vehicle requirements, the cost to manufacture composite structures has proved to be the biggest obstacle to their widespread use. Tremendous progress has been made in developing composite materials and related manufacturing technologies, although the design of composite structures that take advantage of these developments, has not followed a parallel evolution. A revolutionary shift in design integration must be implemented for composite materials to provide the affordable performance they have always promised, and which has now become mandatory for the economic viability of future transportation vehicles.

Investigation of a new design paradigm, combined with the recent emergence of specific processing technologies and approaches, can provide a breakthrough in high performance, low cost composite structures, irrespective of quantity produced. This paper will discuss the impetus for exploiting an alternative approach to structural design as a potential solution to affordability, present some aspects of the "Integrated Airframe" design paradigm that is one possible approach to achieving high performance structures at low cost in both prototype and production quantities, and present the status of an ongoing ARPA/Air Force/Skunk Works program that is defining the future of composite airframe design and manufacture.

Fuel Cells for Transportation: Status and Technical/Economic Needs, Glenn Rambach, Lawrence Livermore National Laboratory

More than 150 years after its invention, the fuel cell is showing strong potential for becoming the successor to the internal combustion engine for powering vehicles. While significant progress has been made in the past 30 years in the direction of bringing fuel cells to commercialization, there are some critical barriers in the technology and economics that need to be overcome. Fuel cell stacks have recently been demonstrated as technically viable in small cars, busses, small trucks and in utility applications. This presentation will describe the current state of several fuel cell technologies and show the technical, economic and infrastructure improvements necessary to make them practical, commercial transportation technologies.

Hypersonic Airbreathing Vehicles/Technologies, James L. Hunt, NASA Langley Research Center

Hypersonic airbreathing horizontal takeoff and landing (HTOL) vehicles are highly integrated systems involving many advanced technologies. The design environment is variable rich, intricately networked, and sensitivity intensive; as such, it represents a tremendous challenge. Creating a viable design requires addressing three main elements: (1) an understanding of the "figures of merit" and their relationship, (2) the development of sophisticated configuration discipline prediction methods and a synthesis procedure, and (3) the synergistic integration of advanced technologies across the discipline spectrum. This paper will focus on the vision for hypersonic airbreathing vehicles and the advanced technologies that forge the designs.

The Use of Steady and Pulsed Detonations in Propulsion Systems, Dr. Henry G. Adelman, Thermosciences Institute; Gene P. Menees, NASA Ames Research Center (retired); Dr. Jean-Luc Cambier, Thermosciences Institute; and Jeffrey V. Bowles, NASA Ames Research Center

Detonation wave enhanced supersonic combustors such as the Oblique Detonation Wave Engine (ODWE) are attractive propulsion concepts for hypersonic flight. These engines utilize detonation waves to enhance fuel-air mixing and combustion. The benefits of wave combustion systems include shorter and lighter engines which require less cooling and generate lower internal drag. These features allow air-breathing operation at higher Mach numbers than the diffusive burning scramjet delaying the need for less efficient rocket engine augmentation. A comprehensive vehicle synthesis code has predicted the aerodynamic characteristics and structural size and weight of a typical single-stage-to-orbit vehicle using an ODWE.

Other studies have focused on the use of unsteady or pulsed detonation waves. For low speed applications, pulsed detonation engines (PDE) have advantages in lower weight and higher efficiency than turbojets. At hypersonic speeds, the pulsed detonations can be used in conjunction with a supersonic combustion engine to enhance mixing and provide thrust augmentation.

A Pre-Mixed/Shock-Induced-Combustion Approach to Inlet and Combustor Design for Hypersonic Applications, John P. Weidner, NASA Langley Research Center

High scramjet performance levels are required for successful hypersonic cruise and space launch vehicles. This paper will suggest a higher degree of inlet combustor integration, to accomplish a higher performance level, by injecting fuel within the inlet so that shock waves that terminate at the inlet throat will induce combustion and result in a shorter inlet and combustor design.

Energy Beam Highways Through The Skies, Dr. Leik N. Myrabo, Rensselaer Polytechnic Institute

The emergence of Energy Beam Flight Transportation Systems could dramatically change the way we travel in the 21st Century. A framework for formulating "Highways of Light" and the top level architectures that invoke radically new Space Power Grid infrastructure, are introduced. Basically, such flight systems, hereafter called Lightcraft, would employ off-board energy beam sources (either laser or microwave) to energize on-board dependent "motors" -- instead of the traditional autonomous "engines" with their on-board energy sources (e.g., chemical fuels).

Extreme reductions in vehicle dry mass appear feasible with the use of off-board power and a high degree of on-board artificial intelligence. Such vehicles may no longer need airports for refueling (since they require no propellant), and could possibly pick up travelers at their homes -- before motoring over to one of many local boost stations, for the flight out. With off-board power, hyper-energetic acceleration performance and boost-glide trajectories become feasible. Hypersonic MHD airbreathing propulsion can enable boosts up to twice escape velocity, which will cut trip times to the moon down to 5.5 hours. The predominant technological, environmental and social factors that will result from such transportation systems will be stressed.

This presentation first introduces the remote source siting options for the space power system infrastructure, and then provides three representative laser/microwave Lightcraft options (derived from historical Case Studies): i.e., "Acorn", "Toy Top" and "Disc." Next the gamut of combined-cycle engine options developed for these Lightcraft are examined -- to illuminate the 'emerging technologies' that must be harnessed to produce flight hardware. Needed proof-of-concept experiments are identified, along with the Macro-Level Issues that can springboard these revolutionary concepts into hardware reality.

High Energy Density Matter for Rocket Propulsion, Dr. Patrick G. Carrick, Phillips Laboratory, Edwards AFB

The objective of the High Energy Density Matter (HEDM) program is to identify, develop, and exploit high energy atomic and molecular systems as energy sources for rocket propulsion applications. It is a high risk, high payoff program that incorporates basic and applied research, experimental and theoretical efforts, and science and engineering elements. The HEDM program is co-sponsored by the Air Force Office of Scientific Research (AFOSR) and Phillips Laboratory (PL/RKF) and includes both in-house and contracted University/Industry efforts. Technology developed by the HEDM program offers the opportunity for significant breakthroughs in propulsion systems capabilities over the current state-of-the-art.

One area of great interest is the use of solid cryogenic propellants to increase the density of the propellant and to act as a stable matrix for storage of energetic materials. No cryogenic solid propellant has ever been used in a rocket, and there remain engineering challenges to such a propellant. However, cryogenic solids would enable a wide class of highly energetic materials by providing an environment that is at very low temperatures and is a physical barrier to recombination or energy loss reactions. Previous to our experiments only hydrogen atoms had been shown to be isolated in solid hydrogen. To date we have succeeded in trapping boron, aluminum, lithium, and magnesium atoms in solid hydrogen[1] all of which could result in large performance increases. Small molecules, such as B2 and LiB, are also of interest.[2] Current efforts involve the search for new energetic small molecules, increasing free radical concentrations up to 5 mole percent, and scale-up of these materials for testing.

The use of cryogenic solid propellants in rocket systems can greatly increase access to space. This technology has the potential to increase payload by as much as a factor of four over current capabilities, allow single-stage-to-orbit options, enable new missions, and provide spin-off benefits in the areas of lasers, explosives and materials.

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Fusion Power and Propulsion for Future Flight, H. David Froning, Jr., Flight Unlimited

Either of two "clean" and compact fusion power and propulsion systems, that are currently being studied and developed, could revolutionize air and space transportation beyond 2000 if their development is continued and is a success. The talk describes these two promising systems and typical earth-to-orbit and interplanetary flight benefits that they could provide. The talk also describes sone commercial applications that these fusion systems are already being used for, together with critical issues that must be resolved before they can be used for future flight.

Advanced Space Propulsion, Dr. Robert H. Frisbee, Jet Propulsion Laboratory

This presentation describes a number of advanced space propulsion technologies with the potential for meeting the need for dramatic reductions in the cost of access to space, and the need for new propulsion capabilities to enable bold new space exploration (and, ultimately, space exploitation) missions of the 21st century. For example, current Earth-to-orbit (e.g., low Earth orbit, LEO) launch costs are extremely high (ca. $10,000/kg); a factor 25 reduction (to ca. $400/kg) will be needed to produce the dramatic increases in space activities in both the civilian and government sectors identified in the Commercial Space Transportation Study (CSTS). Similarly, in the area of space exploration, all of the relatively "easy" missions (e.g., robotic flybys, inner solar system orbiters and landers; and piloted short-duration Lunar missions) have been done. Ambitious missions of the next century (e.g., robotic outer- planet orbiters/probes, landers, rovers, sample returns; and piloted long- duration Lunar and Mars missions) will require major improvements in propulsion capability. In some cases, advanced propulsion can enable a mission by making it faster or more affordable, and in some cases, by directly enabling the mission (e.g., interstellar missions).

As a general rule, advanced propulsion systems are attractive because of their low operating costs (e.g., higher specific impulse, Isp) and typically show the most benefit for relatively "big" missions (i.e., missions with large payloads or V, or a large overall mission model). In part, this is due to the intrinsic size of the advanced systems as compared to state-of-the-art (SOTA) chemical propulsion systems. Also, advanced systems often have a large "infrastructure" cost, either in the form of initial R&D costs or in facilities hardware costs (e.g., laser or microwave transmission ground stations for beamed energy propulsion). These costs must then be amortized over a large mission to be cost-competitive with a SOTA system with a low initial development and infrastructure cost and a high operating cost. Note however that this has resulted in a "Catch 22" standoff between the need for large initial investment that is amortized over many launches to reduce costs, and the limited number of launches possible at today's launch costs.

Some examples of missions enabled (either in cost or capability) by advanced propulsion include long-life station-keeping or micro-spacecraft applications using electric propulsion or BMDO-derived micro-thrusters, low-cost orbit raising (LEO to GEO or Lunar orbit) using electric propulsion, robotic planetary missions using aerobraking or electric propulsion, piloted Mars missions using aerobraking and/or propellant production from Martian resources, very fast (100- day round-trip) piloted Mars missions using fission or fusion propulsion, and, finally, interstellar missions using fusion, antimatter, or beamed energy.

The NASA Advanced Propulsion Technology program at the Jet Propulsion Laboratory (JPL) is aimed at assessing the feasibility of a range of near-term to far-term advanced propulsion technologies that have the potential to reduce costs and/or enable future space activities. The program includes cooperative modeling and research activities between JPL and various universities and industry; and directly-supported independent research at universities and industry. The cooperative program consists of mission studies, research and development of ion engine technology using C60 (Buckminsterfullerene) propellant, and research and development of lithium-propellant Lorentz-force accelerator (LFA) engine technology. The university/ industry-supported research includes modeling and proof-of-concept experiments in advanced, high-Isp, long- life electric propulsion, and in fusion propulsion.

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