Chapter 8 – CONCLUSIONS AND OUTLOOK FOR FUTURE ACTIVITIES

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8.1 LESSONS LEARNED REGARDING THE PLANNED USE OF FLIGHT RESEARCH DATA

As noted in Chapter 1, the unforeseen delays and flight failures occurring in both the HIFiRE and HyBoLT programs required AVT-136 to alter the planned program of work from one building towards an assessment of computational capabilities utilizing flight research data to one focused on simulation validation utilizing benchmark ground test experimental data. While the potential risk associated with planning a Task Group effort on anticipated flight research data was considered during the organization of AVT-136, the group felt the potential benefit associated with access to the flight data warranted acceptance of the increased risk. In retrospect, several key observations associated with the planned utilization of flight research data can be drawn from the experiences of AVT-136.

Planned efforts based on data to be collected in the future face an increased risk of failure due to data unavailability. This most obvious lesson learned from the Task Group experience warrants little further discussion. It should be noted, however, that the research and analysis done in preparation for utilization of the flight data should still be highly useful if the flight data does eventually become available. From this perspective then, there was no "wasted" effort in preparation to analyse the flight data, just delayed return in the research investment.

Existing flight data may not be well-aligned with planned research objectives. Considerable thought within AVT-136 was given to the availability of the existing high-quality flight research data collected by DLR under the SHEFEX I flight experiment. SHEFEX – Sharp Edge Flight Experiment – collected data on the flight performance of a faceted vehicle manufactured from flat sections of thermal protection system material. While the experiment is considered a tremendous success for DLR and a validation of the faceted vehicle concept, the faceted surface made the SHEFEX vehicle poorly suited for exploration of the aerothermodynamic phenomena identified as the scientific objectives of the AVT-136 effort.

Planned flight research data is not well-aligned with the full range of scientific challenges associated with hypersonics. The HIFiRE 1 and HyBoLT experiments were designed to provide flight data on boundary layer transition. Additionally, HIFiRE 1 will provide data on shock/boundary layer interactions. While these data are well-aligned with two of the six topic areas emphasized by AVT-136, only the ESA EXPERT program (which was not part of the planned scope of AVT-136) appears to address some of the gas-surface interaction, rarefied flow and base flow issues that are critical to the development of future hypersonic capabilities. It is clear that there is a significant need for additional flight research opportunities that address a broader range of critical phenomena, especially those associated with increased flow enthalpies.

8.2 PERSPECTIVE ON THE VALUE OF INTERNATIONAL ACTIVITIES

As noted both in Chapter 1 and in Section 6.4 below, 33 conference presentations highlighting contributions to AVT-136 were made by leading researchers in the six scientific topic areas addressed by the Task Group. Such contributions were not funded by AVT-136 and were essentially donated to the Task Group from the existing research programs of the contributing authors. The willingness to contribute research resources to

international working groups organized under RTO has been a persistent characteristic of the hypersonics research community extending back through WG10 and WG18. The members of AVT-136 have given careful consideration to this phenomenon and have concluded the following:

> *Individual researchers are willing to volunteer their time and resources for international collaborative activities because they consider it an honor. A critical aspect of ensuring that participation is considered an honor is to promote the presentation of contributions to the international effort in special conference sessions and issues of archival journals.*

In other words, researchers are eager to contribute their efforts to an international collaborative effort if they have an opportunity to be recognized for their contribution within the open research community. AVT-136 strongly recommends that the Applied Vehicle Technology Panel consider this observation when determining the scope of future working group activities.

Additionally, a consistent theme echoed by the membership of AVT-136 is that international collaboration opportunities provided by RTO Task Groups play a critical role in fostering communication and coordination within the international research community. Despite the advantages of modern internet-based communication, the physical and circadian differences separating the North American and European research communities still deters frequent collaboration. The integrated experiences of the membership of AVT-136 clearly indicate that the RTO-organized efforts such as WG18, WG10 and AVT-136 have played a critical role in the establishment and sustainment of cooperative efforts within the international research community which transcend the limited duration of the Task Groups.

8.3 RECOMMENDATIONS FOR FUTURE AVT EFFORTS IN AEROTHERMODYNAMICS

AVT-136 enjoyed enthusiastic support from the research communities and organizations of the participating countries during the four-year duration of the Task Group. A possible contributing factor to this success is the fact that Task Group meetings were conducted at major research sites in both North America and Europe, resulting in increased opportunities for researchers to become entrained in the program. Another plausible argument is that the six scientific topics addressed by the group facilitated engagement by a broad spectrum of the research community. Regardless of the motivation for such broad support, it is clear that international interest and support for collaborative efforts in hypersonics remains strong. Thus, the members of AVT-136 strongly recommend the continuation of international collaborative efforts in aerothermodynamics under the auspices of the Applied Vehicle Technology Panel.

A description of research topics for potential follow-on efforts to AVT-136 is provided below. One issue that became clear during the course of AVT-136 is that there are dramatic differences in the research communities that contributed to the six topic areas addressed by the Task Group. As a result of the differences in technical challenges, availability of funding, and acceptance of benchmark problems and processes, the unification of multiple research thrusts under a common Task Group may not have been the optimal approach. Inspired by this observation, the potential future efforts described below have a more focused scope of research than that of AVT-136. The intent behind this recommendation is to enhance the efficiency and effectiveness of future efforts. It should be noted that the list below is just a partial list of a broad range of potential activities.

Validation of Numerical Simulations of Shock Wave / Boundary Layer Interactions – Work in this area has historically been strongly supported by members of the RTO community and there is continued significant interest in the topic. Significant advancements in the state-of-the-art have been driven by the assessments of WG18, WG10 and now AVT-136, so it is apparent that the Task Group model works well in this research area. It is recommended that a new Task Group focused on Shock/Wave Boundary Layer Interactions be organized by the Applied Vehicle Technology Panel.

Assessment of Research Capabilities and Needs in Boundary Layer Laminar-Turbulent Transition – In recent years, and especially under AVT-136, this topic area has suffered from a lack of research contributions to Task Group efforts. This deficit appears tied to a dearth of research funding for potential contributors. There is clear international interest in the area and several strong bilateral collaborations resulted from the relationships between researchers fostered as part of the Task Group experience. It is recommended that this topic area be explored in the future as a *Specialists' Meeting* rather than as a Task Group. This approach may elicit a stronger response from the research community and allow the development of a perspective which may be instrumental in the development of future research funding.

Assessment of Predictive Capabilities for Turbulent Heat Transfer – Despite the relatively benign appearance of the topic, design of efficient hypersonic systems is predicated on the prediction of turbulent heat transfer over a variety of surfaces, including those influenced by roughness, material degradation, ablation and catalytic heating. Unfortunately, capabilities to predict such phenomena even on smooth flat surfaces for high Mach numbers are still exceptionally limited. There is significant interest in this topic within the funding agencies of the United States and it is anticipated that there would be significant potential contributions to this topic if it were the focus of a Task Group.

Standard Practices for Catalytic Heating Experiments and Simulations – Interest in this research area produced numerous contributions to the AVT-136 effort. While the AVT-136 effort provided an important assessment of this area, the potential exists to guide further developments in this community through the establishment of widely-accepted benchmark problems and data sets. Such an objective could be accomplished with an initial Specialist's Meeting which could characterize specific research needs and set the stage for an eventual Task Group on the subject.

8.4 CONFERENCE PAPERS PRESENTED IN ASSOCIATION WITH AVT-136

The following papers were presented at the Sixth European Symposium on Aerothermodynamics for Space Vehicles, November 2008, Versailles, France.

S20: RTO-WG043 / Code Validation

- D. Knight, Assessment of Aerothermodynamic Flight Prediction Tools for Shock Interactions.
- D. Gaitonde, Evaluation of CFD for 2-D and 3-D high-speed flow predictions.
- A. Panaras, High-speed Unsteady Flows around Concave Axisymmetric Bodies: Flow Instabilities and their Control.
- S. Schneider, Influence of Freestream Noise on Hypersonic Transition.
- I. Nompelis, Numerical Simulations of Hypersonic Double-Cone Flows with Real Gas Effects.
- S. Borrelli, RTG-043: Sub-Group "Nose and Leading Edges".
- M. Barnhardt, Analysis of the Reentry-F Experiment Using Detached Eddy Simulation.
- J. Olejniczak, An Overview of Radiation Modeling Work for Shock Heated Gas for RTO AVT-136.
- F. Schrijer, Experimental Capsule Afterbody Flow Investigation.

S24: RTO-WG043 / Gas-Surface Interaction I

- M. MacLean, Assessment of Aerothermal Heating Augmentation Attributed to Surface Catalysis in High Enthalpy Shock Tunnel Flows.
- M. Balat-Pichelin, Catalycity of Zirconia and of ZrB2-Based Ultra-High Temperature Ceramics.

- G. Herdrich, Investigation of Catalysis and Reaction Schemes: Ground-based Experiments, Modeling and Extrapolation to Flight.
- M. Cacciatore, Catalytic Activity of Silica Surfaces in Dissociated Oxygen/Nitrogen from AB Initio Calculations.
- A. Schettino, Design and Rebuilding of New Experimental Tests on a Double Cone at Mach 9.

S28: RTO-WG043 / Gas Surface Interaction II

- M. Fertig, SiC Oxidation and Catalysis Modelling for Re-Entry Heating Predictions.
- R. Sayós, Theoretical Dynamics Study of Several Atomic and Molecular Oxygen Processes over a Silica Surface.
- A. Lani, A Residual Distribution Method for Hypersonic Flows in Thermo-Chemical Non-Equilibrium.
- L.M.G.F.M. Walpot, Numerical and Experimental AS-202 Base Flow Investigation.

The following papers were presented at the 48th AIAA Aerospace Sciences Meeting, January, 2010, Orlando, FL, USA.

Session: Overview of AVT-136: Flight Experiment Assessment via Ground Test and CFD

- AIAA-2010-1465 **Shock Interactions Investigations Associated with AVT- 136 (Invited)**
  D. Knight, Rutgers University, Piscataway, NJ, USA; and J. Longo, German Aerospace Center (DLR), Germany.
- AIAA-2010-1466 **Summary of Hypersonic Transition Research Coordinated Through NATO RTO AVT- 136 (Invited)**
  S. Schneider, Purdue University, West Lafayette, IN, USA.
- AIAA-2010-1467 **Experimental Methodologies and Assessments to derive Catalysis relevant Parameters (Invited)**
  G. Herdrich, University of Stuttgart, Stuttgart, Germany.
- AIAA-2010-1468 **Base Flow Investigation of the Apollo Command Module in the Frame of AVT- 136 (Invited)**
  L. Walpot, Advanced Operations and Engineering Services Group, Leiden, Netherlands; P. Noeding, EADS Astrium, Bremen, Germany; F. Schrijer, Delft University of Technology, Delft, Netherlands; and M. Wright, NASA Ames Research Center, Moffett Field, CA, USA.

Session: Shock Interaction Studies Under RTO AVT-136

- AIAA-2010-1281 **A Review of Experimental Studies with the Double Cone Configuration in the LENS Hypervelocity Tunnels and Comparisons with Navier-Stokes and DSMC Computations (Invited)**
  M. Holden, J. Harvey, T. Wadhams, and M. MacLean, CUBRC, Buffalo, NY, USA.
- AIAA-2010-1282 **Numerical Investigation of Double-Cone and Cylinder Experiments in High Enthalpy Flows Using the DLR TAU Code (Invited)**
  B. Reimann, German Aerospace Center (DLR), Braunschweig, Germany; and V. Hannemann, German Aerospace Center (DLR), Göttingen, Germany.
- AIAA-2010-1283 **Numerical Investigation of Double-Cone Flow Experiments with High-Enthalpy Effects (Invited)**
  I. Nompelis and G. Candler, University of Minnesota, Minneapolis, MN, USA.

- AIAA-2010-1284 **An Assessment of CFD for Surface Load Prediction in High-Speed Flows (Invited)**
  D. Gaitonde, U.S. Air Force Research Laboratory, Wright-Patterson AFB, OH, USA.
- AIAA-2010-1285 **Chemically Reacting Flows Around a Double Cone, Including Ablation Effects (Invited)**
  D. Drikakis, Cranfield University, Cranfield, Great Britain.

Session: Contributions to RTO AVT-136

- AIAA-2010-1246 **A Review of Transition Studies on Full-Scale Flight Vehicles at Duplicated Flight Conditions in the LENS Tunnels and Comparisons with Prediction Methods and Flight Measurement (Invited)**
  T. Wadhams, M. MacLean and M. Holden, CUBRC, Buffalo, NY, USA; S. Barry, NASA Langley Research Center, Hampton, VA, USA.
- AIAA-2010-1247 **Modeling Approaches for Gas-Surface Interactions (Invited)**
  G. Herdrich, University of Stuttgart, Stuttgart, Germany.
- AIAA-2010-1248 **Catalysis Phenomena Determination in Plasmatron Facility for Flight Experiment Design (Invited)**
  O. Chazot, F. Panerai, and J. Muylaert, von Kármán Institute for Fluid Dynamics, Rhode-Saint-Genèse, Belgium; and J. Thoemel, ESA, Noordwijk, Netherlands.
- AIAA-2010-1249 **Realization of a Gas-Surface Interaction Test Case for Model Validation (Invited)**
  D. Fletcher, University of Vermont, Burlington, VT, USA.
- AIAA-2010-1250 **CFD Analysis of CUBRC Base Flow Experiments (Invited)**
  M. Barnhardt and G. Candler, University of Minnesota, Minneapolis, MN, USA; M. MacLean, CUBRC, Buffalo, NY, USA.
- AIAA-2010-1251 **Experimental Investigation of the Supersonic Wake of a Reentry Capsule**
  F. Schrijer, Delft University of Technology, Delft, Netherlands; L. Walpot, Advanced Operations and Engineering Services Group, Noordwijk, Netherlands.