Preface

Routine or sustained hypersonic flight, defined for this purpose as speeds higher than five times that of sound, has the potential to revolutionize both commercial as well as military activity. The economic implications of affordable high-speed flight are not restricted to faster transport of people and materiel: even more striking benefits become apparent when such flight is viewed as a key component of an on-demand access-to-space strategy for satellite launch and servicing. From a military standpoint, high-speed vehicles open new options through rapid-response and kinetic-energy-based intercept capabilities.

The present course seeks to disseminate a relatively comprehensive snapshot of the current status of hypersonics research and programs in the international context. To accomplish this goal, contributions were solicited from leading scientists, engineers and technical program managers, representing efforts in multiple nations. The material provides a broad view, and includes historical context, the theoretical and experimental bases of fundamental research, and the manner in which these influence design at various levels in engineering, system and program hierarchies.

Decades of developmental activities on numerous hypersonic vehicle programs have yielded disparate conceptual design approaches to fulfill different missions such as short-duration flight, extended cruise and access-to-space. Nonetheless, many outstanding engineering and basic science hurdles remain in measuring, understanding, predicting and controlling the principal physical manifestations. The rich phenomenology of high-speed flight is perhaps best summarized in the words of Dr. R.P. Hallion of the US Air Force: "…hypersonic flight represents the fullest integration of both the mediums of air and space and the disciplines of aeronautics and astronautics…".

To address the requirement for innovative scientific and enabling engineering advances, evolutionary as well as revolutionary, new programs have been initiated or old ones have been revived. Significant activity may now be discerned in the United States, Japan, Australia, Russia and several countries in Europe, including especially Germany, France and the UK. These endeavors have clarified and sometimes recast many of the challenges currently inhibiting sustained hypersonic flight. Hirschel sets the present course in context with a historical perspective on programs, vehicles and problems.

A unique feature of hypersonic flight is the manner in which multiple physical disciplines couple tightly to yield a wide spectrum of scales. This follows naturally from the fact that the typical flight path for access-to-space encompasses continuum, rarefied and free molecule regimes. A clear understanding of the conclusions based on kinetic theory of gases, and particularly of the pertinent aerothermodynamics is essential. Fletcher summarizes these succinctly. Multiple spatio-temporal scales arise at high-speeds from many other sources as well. Two pervasive phenomena in fluid dynamics are, of course, turbulence and its precursor, transition. At high-speeds, the nature of both includes unique new aspects such as the second instability mode and the impact of baroclinic torques. In one part of their contribution, Arnal and Delery discuss some of the foundations of this field of study. Similarly, other distinguishing characteristics arise from the high-temperatures encountered, such as thermo-chemical non-equilibrium and radiation. The physics of these effects require knowledge of chemical and molecular kinetics, which form the basis of the lecture by Magin and Barbante.

Shock-waves, which are inevitably present, also generate new constraints on propulsion, control surface effectiveness and, depending on application, may introduce aero-optical considerations as a coupled design factor. Shock wave interactions with other shock waves and boundary layers yield many dominant flow features such as separation, vortical structure formation, turbulence amplification and high heating. Much research has been performed in this area, major aspects of which are also covered by Arnal and Delery.

For both basic and applied research, simulation methodologies are likely to play an ever more integral role in analysis, especially to complement often difficult and expensive ground and flight testing. Specific strengths of verified and validated numerical methods include generation of deeper understanding of phenomena not accessible to experiment, and exploration of new design and control concepts. Longo addresses this rapidly maturing area by considering the main modelling issues.

The presence of ionized flow often triggers coupled electromagnetic effects. Although these can be problematic, the fact that suitably configured external magnetic and electrical fields can exert force and energetic interactions on the flow has spurred the proposal of ingenious flow control procedures. Often denoted plasma-based, such methods overcome the failure of many conventional methods in the hypersonic environment, by obviating moving appendages and provide "action-at-a-distance" control. These processes may also fulfill energy extraction and management functions for on-board activities. The science behind these techniques, their constraints and some promising methods of both local and global control are summarized by van Wie.

The basic phenomena outlined above form the framework through which the harsh environment encountered by high-speed vehicles is established and which pose daunting technological challenges at the system level. Major aero-structural constraints arise from extremely high drag, catastrophically large heat loads and the related need for energy management. Separate aspects of these factors are addressed by Prabhu, who in one of his two presentations discusses the aerothermal environment in the trajectory of a hypersonic vehicle, and by Kolodziej, who addresses solutions based on thermal protection systems and structures.

Perhaps the most prominent pacing item in hypersonics is the configuration of the propulsion system. The significant cost benefit of leveraging air-breathing technologies, such as scramjets, will only be realized after numerous problems have been overcome. These encompass not only mass-capture, mixing and combustion processes, but also airframe-propulsion integration in all parts of the flight envelope from take-off to cruise to landing. Some of the cutting-edge efforts in this area are addressed independently by Falempin and by Segal in the first of his two lectures.

Vehicles operating over a range of speeds pose significant difficulties in ensuring balance in all segments of the envelope, since it is generally the case that subsystems do not operate optimally over the entire speed range. Trim drag penalties and catastrophic lack of control may then result especially since response time is often very short, and options are limited. System level vehicle control is the topic of two lectures, the first by Prabhu on vehicle control systems, and the second by Koppenwallner on air data systems and flight instrumentation issues.

A major constraint in the development of hypersonic systems has been their expense, which has called into question their cost-effectiveness. Trade studies and optimization techniques will therefore play a key role in refining vehicle specifications by minimizing cost while maximizing capability and reducing risk. Moulin discusses various such considerations at the system level.

Flight tests are not only an integral component in the development process of any vehicle, but indeed are the ultimate arbiters of success. Particularly at high speeds, and given their relative expense, the design of flight tests requires careful thought on configurational details as well as instrumentation and objectives. These issues form the basis of the lecture by Muylaert.

The focus of basic and system level research must be consolidated into integrated and well motivated programs designed to satisfy major objectives and to provide a focus for subsequent research efforts. For example, a weaponized system may have additional constraints arising from the need for high-altitude maneuverability and weapons integration and release. This task of determining the elements of a vehicle development program typically includes a significant historical element to account for the evolution of the

mission, together with an iterative compromise between desired and available capabilities. Two contributions, both on reusable launch vehicles, highlight the pragmatic nature of program development. The first, by Erbland, elucidates requirements and objectives of various programs, while the second, by Segal, discusses near-term strategies for future vehicles.

Although the material addressed by this lecture series is very broad in scope, in each area the instructors have made judicious choices on the specific subset of topics covered and in the level of treatment. It is the hope of the organizers that the course demonstrates the connection between the diverse fundamental phenomena encountered in hypersonic flight to system level constraints and ultimately to current programs. We believe that such a comprehensive treatment will help focus attention on the truly integrated multi-physics research investigations that must be nurtured. It will also hopefully provide guidance in the broader goal of designing lower cost hypersonic vehicles to serve space-access as well as various sub-orbital purposes.

We express our sincere appreciation to all the lecturers for giving generously of their time and effort to make this venture a success. In addition to the co-directors, the organizing committee includes Prof. Gérard Degrez, who took the primary steps in initiating the course, and Prof. Herman Deconinck, who was most supportive of this endeavor. We also thank the VKI staff for fulfilling the many administrative functions with remarkable efficiency. Finally, we wish to express our gratitude to the NATO Research and Technology Organization, as well as the European Office of Aerospace Research and Development (Monitor: Mr. Wayne Donaldson) for their generous sponsorship.

Datta V. Gaitonde
Air Vehicles Directorate
Air Force Research Laboratory
Wright-Patterson Air Force Base, OH, USA

Douglas G. Fletcher
Aeronautics & Aerospace Department
von Kármán Institute for Fluid Dynamics
Belgium