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AERODYNAMIC HEATING IN HYPERSONIC FLOWS

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ABSTRACT

Aerodynamic heating in hypersonic space vehicles is an important factor to be considered in their design. Therefore the designers of such vehicles need reliable heat transfer data in this respect for a successful design. Such data is usually produced by testing the models of hypersonic surfaces in wind tunnels. Most of the hypersonic test facilities at present are conventional blow-down tunnels whose run times are of the order of several seconds. The surface temperatures on such models are obtained using standard techniques such as thin-film resistance gages, thin-skin transient calorimeter gages and coaxial thermocouple or video acquisition systems such as phosphor thermography and infrared thermography. The data so collected is usually reduced assuming that the model behaves like a semi-infinite solid (SIS) with constant properties and heat transfer is by one-dimensional conduction only. This simplifying assumption may be valid in cases where models are thick, run-times short and thermal diffusivities small. In many instances, however, when these conditions are not met, the assumption may lead to significant errors in the heat transfer results. The purpose of the present paper is to investigate this aspect. Specifically, the objectives are: (1) to determine the limiting conditions under which a model can be considered a semi-infinite body, (2) to estimate the extent of errors involved in the reduction of the data if the models violate the assumption, and (3) to comeup with correlation factors which when multiplied by the results obtained under the SIS assumption will provide the results under the actual conditions.

To achieve the above goals, the transient one-dimensional conduction equation in a semi-infinite medium with a convective boundary is analytically solved and temperature history graph is produced. From this graph, the minimum thickness of the model for which it can be considered SIS for a given run-time or vice versa is determined. This is done by arbitrarily assuming that the model behaves like SIS if the rise of the temperature (from the initial uniform temperature) on the back side of the model is less than one percent of the rise on the front (heating) side of the model. From this limiting condition, a plot of critical thickness versus critical run-time is generated for a given material and wind tunnel conditions. This curve would be useful in designing test models and run-times such that the SIS premise is not violated. Conversely, if the model thickness and material, run-time and wind tunnel conditions are known, the percent deviation from the ideal conditions can determined.

In order to account for the finite size of the model under actual conditions, the one-dimensional transient heat conduction problem in a finite slab with one side subjected to convective boundary and other insulated is analytically solved. The results are compared to the solution obtained under the ideal conditions; the difference in the heat transfer results is correlated to the percent deviation of the model from the ideal conditions, and the correction factors are developed. These factors are expected to be valuable tools to experimental researcher in estimating realistic aerodynamic heat transfer coefficients and heating rates under the actual conditions and applying them with confidence in designing hypersonic vehicles.

Aeronautical Engineering as a Context for a Course in Mathematics

by

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During the tenure of this fellowship, the author began the development of a highly non-traditional approach for a mathematics course intended for undergraduates who are non-science concentrators.

At many institutions, these students are compelled, for one reason or another, to take a course in mathematics. Such a student who is at once mathematically ambitious and capable will sometimes take a course in beginning calculus. Others less well endowed find minimal methods of satisfying the requirement.

Typical examples are high school level course in trigonometry or algebra. Perhaps a statistics course of some sort, or a so-called finite mathematics course. It is a well-established fact that the majority of students who emerge from such courses are left with a bad taste in their mouths.

The author has undertaken another approach akin to the version of mathematics that working engineers use. Their perception of mathematics is, in the main, an entirely pragmatic one. For an engineer, mathematics is not organized by the unifying characteristics that are the framework of mathematicians. An engineer uses enough of a technique to solve a problem and then the technique is left until needed for the next problem.

It is not the contention of the author that mathematics for professional engineers should be taught in the fragmented way it is actually used. The efficiency and unity of the discipline that are ingrained in every mathematician are most likely the best guides for conveying serious mathematics to serious users. There are simply too many applications of mathematics to trust it to an exposition by example.

But only the rare non-science student is a serious user. This means that while individual topics in a terminal mathematics course are supplied with 'realistic' applications, there is no useable motivation for the entire undertaking. Thus does the student conspire with the instructor: I am taking this course because I have to, I will never use it, and I don't understand how anybody else uses it.

Indeed, this a view taken by many students already in high-school. One potential consumer for the course under design is the prospective middle school teacher. As undergraduates, these students are unlikely to get any sense of the role of mathematics in the modern world. They are trained in their college course(s) that mathematics is one topic after another in the text book. And that is the way they teach *their* pupils in school, with catastrophic results for those who need to take mathematics in high-school.

That part of the material developed so far is still in draft stage. The working idea is to display some obvious, though perhaps mysterious, aspect of powered flight, and then expose a mathematical technique that might be used to help understand the problem. True to the code, any such technique is developed only so far as it is needed. There is no formalism, only an attempt to show students that working things out on paper is cheaper than a multitude of experiments.

In the end, the author expects to construct a text that is not beginning physics and certainly not beginning aeronautical engineering. No problem is undertaken unless it is both obvious and contains some mathematics that is accessible to intelligent though untrained students.

To date, we have worked out, or partially worked out the following topics.

1. Cross winds, paralellogram addition and vector decompostion.

2. Navigational headings, compass arithmetic. Polar coordinates.

3. Moments, center of gravity, requiring in messy cases some numerical integration.

4. Combining compasses on the surface of the earth. Map projections, geometry. Great circles as distinguished from navigational headings.

5. Wind distributions. Optimal orientation of runways. More numerical integration.

It remains to open the dynamical can of worms. This is obviously going to be very difficult. But there is a lovely lesson: mathematicians and engineers do not know everything they would like to know about fluid flow.

It is the author's belief that powered flight, as a physical phenomenon, remains a great mystery to most lay people. It is actually a great mystery to most mathematicians. If one could succeed in exposing something of this mystery and also exposing the usefulness of mathematics in that context, a good course in mathematics may result.