Abstract

Some of the accomplishments made during the past decade toward the solution of atmospheric problems associated with aerospace vehicle design and operations are reviewed. Improved measurement systems, atmospheric models and data applications, and some current aerospace related atmospheric problems are discussed. A summary of the planned Space Shuttle and some of the atmospheric properties which will be of concern in the design and operation are given.

1. Introduction

This paper reviews the progress and selected accomplishments over the past decade in aerospace meteorology. For our purposes, aerospace meteorology includes those aspects of meteorology (measurement, analysis, and study) that are primarily influenced by the requirements of missiles, space vehicles, and aircraft. In some cases a multiplicity of requirements has resulted in contributions to aerospace meteorology. Because of the broad nature of the subject and the limited time available, many of these accomplishments will be only mentioned. Although some are well known, for instance, satellite photography, others, such as detailed wind profile measurements, are not.

A few problem areas related to the needs of aerospace meteorology are discussed. Here again, most needs are common to other user’s requirements. In some cases, a solution to the problem primarily provides improved reliability and confidence in the planning for operation of an aerospace vehicle. For other problems, a firm deterministic solution would permit selective design capabilities.

Finally, this decade is expected to witness the evolution of a space shuttle, a craft which will embody many characteristics of space vehicles and conventional aircraft. Some of the currently planned shuttle capabilities with respect to their atmospheric influences on design and operation needs, and some selected significant atmospheric factors in the design and operation of a shuttle will be reviewed.

In general, the past decade of accomplishments in atmospheric measurements has been dominated by the introduction and adaptation of automation, electronics and communications. Although this adaptation has produced dramatic results (for instance, meteorological satellites), achievements in wind measuring systems have been slow and restricted. Progress in the next decade is expected to rely heavily on the exploration of automation concepts and remote sensing (from satellites, in particular). We believe there will develop a renewed realization and application of the mass of atmospheric data being acquired daily. These data, for which many people devote dedicated hours to develop sensors, still suffer from inadequate analysis and study with respect to applications. The achievement of quality control, timely communications and display, model development, and interpretation for specific engineering problems should receive the vital attention it deserves. Aerospace meteorology has often identified problems which produced the necessary attention, and at the same time provided basic and important contributions to others having more general requirements. This relationship is expected to continue.

2. Some achievements in atmospheric measurements

Several achievements in atmospheric measurements actually began in the 1950’s, a few even earlier. Progress has been slow in some cases. On occasions, problems were recognized, sufficient support and priority were furnished, and the appropriate measurement scheme(s) were pulled together as a system. On other occasions, the problem has been one of economics; that is, some problems became trade-offs in the cost of the solution of the problem versus the consequences of living with existing capabilities. In other words, the wheel that squeaks the loudest at the time often gets the oil (resources and recognition).

The list below outlines the main achievements to be discussed in this paper.

1. Low level (surface to ~ 1 km)
   a) Towers
   b) Tetroon
   c) Visibility
   d) Anemometers

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1 Presented at the 7th Space Congress, 24 April 1970, Cocoa Beach, Fla.
2. Upper air (~1 km to ~30 km)
   a) Rawinsonde—ADP, transponder
   b) Jimsphere/FPS-16 radar
   c) Weather satellite—clouds, temperature, and storms
   d) Weather radar

3. High altitude (>30 km)
   a) Rockets
      1) Chaff
      2) Chemical trails
      3) Sondes and probes—sensors
      4) Falling sphere
      5) Gun probe
      6) Grenade
      7) Meteorological Rocket Network
   b) Satellite—aeronomy
      1) Density (neutral)
      2) Electron density
      3) Radiation
      4) Meteoroids

4. Developmental
   a) Remote sensors—optical, IR, UV, MW
   b) In situ sensors—ground- and vehicle-based.

   a) Low level (surface to ~1 km)

Low level atmospheric measurements are often restricted to a ground-based platform for support. For measurements up to about 150-m height, the use of instrumented towers is preferable. (Certain research problems have used towers up to heights of 500 m.) Aerospace problems associated with ground wind loads and abort have produced the need for specialized towers, which are now common on the various test ranges. The NASA tower at Kennedy Space Center, which has been instrumental in the development of several new approaches to space vehicle ground wind problems, contains dual-mounted sensors to avoid tower influences on the wind. It operates efficiently to provide timely and accurate data. Similar towers have been constructed at White Sands Missile Range, Wallops Island, and other sites. Above a height of about 150 m, we find the balloon-borne sensor with ground tracking still the primary tool. Tetroons (constant volume balloons balanced to float at given density altitudes) have been developed and used extensively during the past decade. These balloon sensors are of value in tracing air currents, a knowledge of which is necessary in the field of atmospheric diffusion. Use of tetroons has resulted in establishment of models of wind flow which cannot otherwise be acquired for a local area. This information is useful in making design and operational decisions related to the use of hazardous by-products of power plants and vehicle engines.

Visibility for aircraft operations is an age-old problem. What an observer sees on the ground frequently is not what a pilot sees on take-off or landing. This is still a critical parameter despite the highly publicized development of “all weather” landing systems. The successful and safe day-to-day operations of aircraft still depend in a large measure on the pilots’ ability to see, particularly the last hundred feet or so of the landing operation. The development of the transmissometer was helpful, but multiple installations are still needed on runways to provide adequate input to display panels.

The anemometer probably is one of the most important sensors for meteorological measurements, and has been developed by the largest variety of methods. Because of its importance, almost every conceivable means has been exploited to measure wind velocity near the ground. The past decade has seen new or renewed emphasis on sonic, drag sphere, optical (laser), impeller, cup, hot wire, acoustic-radar, and other schemes both remote and in situ. This area still remains a problem, primarily because of the continued need for a platform on which the sensor must be mounted. The resolution of cup and impeller anemometers has been extended significantly in the 1960’s. Operational units will now provide data up to about one Hertz with research oriented sensors having considerably higher response capabilities.

Automatic stations to provide standard measurements of temperature, pressure, wind, precipitation, etc., have been developed and made operational by the timely application of automation techniques. The polar region programs, ocean buoy programs, and military programs have benefited from these developments, along with local weather stations and private users. The “labor” has been taken out of ground measurements of “conventional” meteorological parameters, and nearly all locations use an “automatic” observing station concept to some degree.

b) Upper air (~1 km to ~30 km)

This area of the atmosphere has seen both some of the slowest developments and some of the most dramatic accomplishments in measurements. For example, the basic technique developed in the 1940’s is still used in the measurement of wind, at least for general meteorological use. On the other hand, techniques for sensing of cloud cover on a large scale have made a quantum jump in development. This is the altitude region in which our “weather” occurs, aircraft operate, and missiles/space vehicles experience their major atmospheric influences. It is very important not only to aerospace problems, but to man’s problems in general.

The rawinsonde is still the principal method used to measure wind, temperature, pressure, and humidity in the upper atmosphere. It is hoped that, for synoptic purposes, the satellite will result in great progress in sensing during this decade. At the moment, however, there appears to be no sign that the need for a ground-based measurement system will disappear. The rawinsonde technique uses a radio direction finder with balloon-borne telemetry package. Economy is one of the main factors in the technique selected. The last decade has seen the addition of a remitter sonde to provide
slant range capability and automatic data processing. The latter has been the more significant accomplishment, since accuracy of the system has remained about the same since the early 1950's. The system's resolution appears to satisfy the general synoptic user, but the system is not capable of providing detailed data on the vertical wind profile structure critical to space vehicle structural design.

The FPS-16 Radar/Jimsphere system (see Fig. 1) is a significant improvement in measurement capability. Surprisingly enough, a number of schemes were studied, including remote sensing. (The original idea was to develop a system independent of balloons with the hope of a rather rapid wind profile measurement capability. "All-weather" requirements eliminated most proposals with adequate resolution, with perhaps cost and complexity eliminating the rest.) The system uses a two-meter constant volume super-pressure mylar aluminized balloon tracked by a high precision FPS-16 radar. It is operational at most test ranges, and has provided significant design, operational, and research data.

The meteorological satellite is obviously the greatest single improvement in weather observation. This next decade should see continued improvement in our ability to observe and transmit timely pictures of the Earth's weather patterns to all users. Quantitative measurements of the vertical temperature structure have been achieved and should contribute especially to synoptic meteorology needs.

Weather radar has become an everyday accepted tool. This has been accomplished during the past decade by integration of the radar system into a national network. This system is capable of probing several hundred miles to provide quantitative, as well as visual, data on atmospheric processes.

c) High altitude (~30 km)

Measurement at high altitudes has seen its primary development because of the availability of large and small rockets without which measurement would be impractical. For relatively small rockets, a variety of sensors has been used (see Fig. 2). Each has its merits and shortcomings, however. Probably the most satisfactory is the falling-sphere sensor, which measures density based on the drag of the sphere and wind velocity, both obtained from radar tracking. Until the past decade, little was known of the wind flow patterns and thermal conditions at these altitudes. Formerly assumed to be a "quiet" area of the atmosphere, it was soon learned that high altitudes were very significantly dynamic. Fortunately, most aerospace systems that operate at these altitudes have low dynamic pressure conditions which minimize the influences of large wind velocity ranges. However, density variation information is of major importance for entry heating calculations. Fig. 2 illustrates a typical rocket system using a parachute-borne sensor. Some of the first tests of meteorological rocket systems took place at Cape Kennedy. The outgrowth of these tests was the subsequent development and establishment of meteorological rocket sites at a number of locations. Some of the principal sites are shown in Fig. 3. A number of these are organized into "networks."

The satellite, in addition to its use for weather observation, has provided the basic tool for orbital altitude measurements of atmospheric parameters. In particular, the behavior of the satellite in the presence of atmospheric density and its relationship to satellite drag have been a rich source of data. These data have been used extensively in the development of larger satellites, mission analysis, lifetime prediction, and are now being used in space-station studies. Most satellites have had some type of radiation measurements on board, and some have been used to measure the effects of meteoroids on the craft.
3. Some accomplishments in atmospheric models, data application, etc.

All measurements of the atmosphere have, or should have, a purpose. This purpose is frequently to provide knowledge on current conditions or to estimate future conditions for operational decisions. A major purpose of atmospheric measurements is to develop models of the atmosphere for application to design problems, mission analysis, and prediction schemes. Given below are some achievements of the past decade. Some may be familiar; all have been important in making decisions on design, mission time lines, and operations.

Some of the atmospheric models already developed are:
1) Standard and reference atmosphere models
2) Orbital density (time variant) models
3) Ground and inflight wind models
4) Turbulence model (vertical profile)
5) Worldwide cloud cover model
6) Numerical prediction models
7) Pre-launch monitorship of winds and flight simulation models, and
8) Exposure period probability models.

Other major developments have been the audio-visual communications and computer application to aerospace meteorology. Now under development are 1) four-dimensional atmospheric models, 2) detailed prediction models, and 3) weather modification.

The development of the U. S. Standard Atmosphere in 1962 and the supplements thereto in 1966 were of major importance in providing common baselines on atmospheric temperature, pressure, density, etc., as functions of altitude. The range reference atmospheres developed under the direction of IRIG (Inter-Range Instrumentation Group) were a major accomplishment in making available knowledge on atmospheric parameters over each test range. Wind model development saw the definition of consistent inflight wind parameter representation for use in vehicle design studies. Ground winds became critical as vehicles grew in height, and definition of variable wind with height models based on selection of “reference levels” contributed significantly to the engineering understanding and application of these data. The first turbulence spectral model based on the knowledge gained from detailed wind profile (in the vertical) measurements was established.

Exposure period probabilities were applied during the past decade as a decision-making tool. These probabilities, which are based on a large number of records of atmospheric data, permit a vehicle design to be based on its expected “exposure,” for example, to ground winds. The prelaunch monitorship of wind conditions and flight simulation as before the launch of a space vehicle has reached a new high in ensuring safety within the design limits. Fig. 4 illustrates a typical prelaunch sequence of profiles each used in the simulation of vehicle flight in order to establish a go/no-go condition. The resolution is such that no additional “padding” is necessary to account for lack of resolution in the wind profile measurement. These data also made possible the previously mentioned turbulence model development and revealed the existence of features in the wind profile not heretofore observed or realized.

A computerized model of the worldwide cloud cover has been possible because of the achievements in availability of data records. Satellite data have added to this capability. Here again, the need for a solution to an aerospace problem resulted in a solution to other problems. Numerical weather prediction or simulation has made great strides in the past 10 years, so much so that we have now reached the threshold of a Global Atmospheric Research Program to establish the ultimate capability in atmospheric prediction. One key to the success of numerical weather prediction has been the recognition of scales of motion associated with various atmospheric phenomena: 1) large-scale air-mass cyclones/anticyclones, 2) mesoscale thunderstorms, 3) medium-scale tropical cyclones, 4) small-scale cumulus cloud/tornado, and 5) microscale dust-devil/transport of heat, etc.

Developmental work in weather modification has illustrated the powerful potential of this area of investigation. Fog dissipation, stratus dissipation, precipitation
development or suppression have all been demonstrated. The extent this can be refined or made practical for the benefit of all concerned has yet to be established. The next decade should see considerable progress, as in numerical weather prediction. Worldwide models (latitude, longitude, altitude, and time) should become a reality in the next decade. These models will provide consistent inputs for various engineering studies in aerospace.

4. Some current aerospace related atmospheric problem areas

To determine what constitutes a "problem" area is sometimes difficult. A problem may range all the way from one situation, the solution to which is necessary for an action to be taken, to another situation, whereby the solution is simply to make the condition of less concern — either to the program or to an individual involved in some aspect of the program. In either event, the solution (full or partial) frequently enables other related problems to be more easily dealt with. Such is the case with the problems indicated in the following list:

1) Remote sensing of winds—ground, aircraft, and satellite based
2) Short and medium term forecasts for specific location with high degree of confidence:
   a) Peak ground winds
   b) Severe weather (thunderstorm, tornado, hurricane)
   c) Electrical activity
   d) Peak inflight winds
   e) Cloud cover and visibility
3) Rapid upper air wind profile measurement (desired, but questionable as critical item)
4) Dynamics of upper atmosphere—especially > 30 km
5) Data records/data banks
   a) Quality
   b) Completeness
   c) Quantity
6) Design criteria—application and interpretation.

Remote sensing of wind velocity appears to be a significant problem, although, in limited ways, it has already been solved. However, each solution involves constraints that, to date, prohibit its use except in very controlled experimental situations. From a general meteorological viewpoint, the satellite remote sensing of wind velocity is probably the most critical need. Aircraft remote sensing of clear air turbulence would rank a close second. Ground-based remote sensing would contribute to airport wind monitorship, and could be used on board aircraft carriers and in space vehicle operations. However, it must be emphasized that merely to obtain a "measure" of the winds by remote means is not adequate. One must sense the wind velocity with the required resolution, time interval, and spatial distribution at the location desired and under the necessary atmospheric conditions or operational constraints. Otherwise, only another limited use research tool is produced.

With all the current publicity on two-week forecast goals and related endeavors, we would assume that the accurate short-term forecast was a reality. First, a mention of "weather forecasting" produces a vast range of meanings in the minds of those listening. This may range all the way from the long wave index in the upper atmosphere to the question, "Will it rain at 2:00 p.m. tomorrow afternoon on launch pad '98" or "What will the peak wind speed be at 60 feet above ground level in an equipment preparation area?" This, of course, makes the problem difficult. We in the aerospace community often think of the day when we will be able to "design out" to a large degree the atmospheric extremes; i.e., with the knowledge of the existence of a relatively precise six-hour prediction capability for, say, ground winds, then one may be able to design an aerospace vehicle for which protection would be provided with dependence on a ground-wind prediction for action relative to a more modest design wind limit. However, this is not now practical, since either down time would increase or the risk would increase with current deterministic prediction values. For most aerospace operations, the need for improved short (few hours) and medium (24 to 36-hour) forecasts far outweighs the need for longer term gross forecasts of mean circulation patterns. It is hoped that renewed interest and efforts on the mesoscale prediction problems will develop. The changes in atmospheric conditions are the critical forecast requirement, not the continuation of current conditions which show high persistence. Therefore, forecast accuracy studies may be very misleading relative to predictions for the important mesoscale phenomena.

The need for a more rapid wind profile measurement system continues to exist. However, it is not so critical since the development of the Jimsphere/FPS-16 radar system and its related rapid data reduction and transmission capability. Unless a rapid measurement scheme can be developed that provides basically the same data accuracy and reduces the profile measurement time to about one-third or less of the current one-hour to 18 km altitude time interval, then it is questionable if the development will be of major significance.

In the atmosphere above 30 km altitude (see Fig. 5) there exists a critical need for measurements. The region between ~ 30 km and ~120 km is observable only by rocket-borne probes. The area ~ 50 km to ~90 km is critical for entry heating studies. Data are meager, particularly in the upper part of this altitude region. Although significant progress has been made in the past decade, sensor development has been difficult. These altitudes contain the basis for boundary assumptions on which atmospheric models are created. Limited data from very low orbiting satellites indicate rather dramatic behavior of the atmosphere at these altitudes. Since space vehicle designs are based on the non-nominal variations in atmospheric parameters, it is necessary to estab-
lish probable limits for use in design studies. Unfortunately, the per data point expense and complexity of the rocket system increases with altitude of measurement until the lower orbit region for satellite data is reached.

Data records and data banks are very important to the developer of models and engineering applications of data. This is being recognized by more people and organizations as they focus on the subject of environment pollution problems in general. One needs relatively large amounts of dependable data, which are often acquired at considerable cost, for application to numerous problems. The value of quality control for the records seems obvious when the replacement costs and the time required to re-establish the records are considered. Progress has been made in the last few years through inter-agency cooperation, and it is expected to continue. Finally, the problem on application and interpretation of environmental data for design criteria is mainly one of communications.

5. Desired shuttle capabilities and significant atmospheric factors

A space shuttle is now under consideration as the primary space transportation system development for this decade. Based on statements in the current Phase B Space Shuttle System Program Definition distributed by NASA Headquarters in February 1970, the atmospheric interface implications will be reviewed. Fig. 6 illustrates one concept for the shuttle. This is not meant to imply a NASA acceptance of this configuration or operational mode. It illustrates that the design of a space shuttle involves the combined requirements for the design of both airplanes and space vehicles.

In the performance of space missions, the space shuttle must be designed to operate both in the Earth's atmosphere and in space. Some of the current desired capabilities which may be affected by the atmospheric environment are listed below:

1) Many mission cycles
2) Minimum sensitivity to weather conditions
3) All azimuth launch
4) Automatic landing—FAA Category II conditions
5) Self-ferry
6) Go-around landing
7) Launch turn-around—two-weeks
8) Launch/landing site(s)
9) Vertical take-off—horizontal landing
10) Launch
   a) Twenty-four hour return to preselected site
   b) Within two hours from standby
   c) Sixty-second launch window
11) Booster return to launch site.

All atmospheric elements and properties which are of singular concern in the design and operation of the present Apollo program and high performance aircraft become combined in the design and operations of the space shuttle. The familiar terrestrial effects of wind loading (ground wind, lift-off, inflight), weather (thunderstorms, visibility, lightning hazards), and aerothermal loading (aerodynamic heating) in the design and operations of the Apollo and high performance aircraft as separate manned transportation systems will be combined in a more complex manner for the space shuttle. The proposed space shuttle mission requirements will make even further demands to minimize the effects of the Earth's environment on the operations of this space transportation system. An outline of desired design capa-
bilities and feasible operational phases which are taken from management briefings are presented only for an overview of design and operational problems pertinent to the Earth's environment. Discussions center on winds near the ground (10–150 m altitude), weather, inflight winds, and atmospheric models for aerodynamic heating.

Note that the weather conditions must be favorable at launch not only for the launch phase but also for the booster fly-back and landing. The proposed frequency of missions and short recycle time (approximately 2 weeks) for the missions will require that systems sensitive to meteorological factors must be minimized. This means that the systems must be designed to minimize operational constraints due to meteorological factors (primarily weather and wind loading) which may cause schedule delays.

Some of the more significant atmospheric factors to be considered for the design and operation of the space shuttle are:

1) Wind loads
   a) Ground—prelaunch, launch, and landing
   b) Inflight—boost, booster return and orbiter return
   c) Ferry
2) Thermal loads
   a) Booster phase, booster return
   b) Orbiter return
3) General atmospheric
   a) Prelaunch—temperatures, precipitation, electrical, etc.
   b) Launch operations—thunderstorms, severe weather
   c) Flight—orbital radiation, meteoroids
   d) Landing—severe weather, visibility
4) Coordinated and consistent natural environment
   a) Terrestrial
   b) Space.

a. Wind near the Earth surface

Since it is very difficult to describe the characteristics of the wind profile completely in a deterministic sense, statistical methods have been found to be most useful in describing the wind field for a number of aerospace vehicle design and operational problems. The statistical methods require an appropriate data sample. The samples often require considerable effort in their collection and evaluation. The resulting statistical descriptions must be applicable to the engineering problems. Also, a methodology must be established to calculate the desired vehicle responses to produce the required vehicle parameters; e.g., bending moments caused by the wind force. From the resulting vehicle engineering parameters and wind statistics, objective decisions can be made in establishing design risk. From design trade-off analyses, the development cost and the impact that operational constraints would have on the missions can be determined. The wind statistics for the 10–150 m layer have important applications in the following areas:

1) Wind loading on vehicle while erected on launch pad and supporting structures
2) Interface design of vehicle and supporting structure; e.g., clearance requirements between supporting structure caused by vehicle deflections
3) Wind loads on the vehicle at lift-off (the so-called "twang loading" caused by the transition from base hold-down at launch release to a free-free mode)
4) Tower or other supporting structure clearance at lift-off (vehicle drift).

The concept of exposure period statistics has been previously mentioned. An exposure period statistic, when used in connection with ground wind applications to vehicles, gives a measure of probable risk of exceeding the vehicle design or operating limits for the vehicle exposed to the wind.

b) Weather

It is not considered feasible to design the Space Shuttle to fly through any and all weather conditions. The wind forces in a thunderstorm are considered as potential hazards to the structure. Because of the uncertainty involved in performing pre-flight evaluations for flights through thunderstorms, such flights should be avoided. During a close advance of a hurricane, the ranges are normally secured from space operations. Detailed statistics on thunderstorms and hurricanes are available and can be used in evaluating range operations. In addition to performing statistical analyses of the various meteorological elements of interest in the design and operations of the Shuttle as individual elements, composite statistics taking several elements simultaneously can be analyzed.

Visibility and clouds are considered as weather within the context of this discussion. Should the design of the launch vehicle or orbiter be unsuccessful for landing under a cloud ceiling less than 200 ft and visibility less than 1/2 mile, then a comparison of these conditions for potential launch/landing sites for mission planning purposes seems appropriate.

c) Inflight winds

Descriptions of the wind are required to establish structural and control system designs. The relative importance of the wind effects on structural loading may vary according to the flight phases of the space shuttle. Since the launch sites will be limited, detailed studies on the structure of the wind profile for the selected launch sites is feasible. The launch vehicle (or booster) flyback and ferry operations, and the orbiter after reaching cruise altitude (say near 12 km) upon return to Earth from a space mission, will require wind descriptions more like that for aircraft. The operating range in the Earth's atmosphere is no longer restricted to a few launch sites.
The required wind descriptions for the shuttle design for Earth re-entry altitude at approximately 120 km down to cruise altitude near 12 km probably holds the greatest uncertainties. These uncertainties arise from both our lack of knowledge in describing the wind structures over the region up to 120-km altitude and the effects wind forces may have on a high lifting body at these altitudes. To meet the mission requirements for maneuverability, cruise flight at low altitudes, landing capability, and reduction of aerodynamic heating, a high lift-to-drag aerodynamic configuration has been proposed. These wind effects could enter the design problem in some unforeseen complex manner. It is conceivable that horizontal and vertical wind shear and turbulence effects on the control system design will be the most important aspects of the design problem for this flight phase. Here it is tacitly assumed that the boost flight phase and abort requirements will dictate the structural design due to wind loading.

d) Atmospheric models for aerodynamic heating

The control of aerodynamic deceleration loads and thermal loads caused by aerodynamic heating is a primary problem in the design of vehicles entering the Earth’s atmosphere from space. The structure of ambient density versus altitude has been recognized as the most important atmospheric variable contributing to aerodynamic heating both in the launch phase and in entry into the Earth’s atmosphere. To reduce the weight and the cost of refurbishing the heat protection system, a re-radiative system appears more attractive than an ablative system such as one used in the Apollo. The heating rate \( q \) to stagnation point on a spherical surface is approximately proportional to the product of the square root of density \( \varphi \) and the cube of the velocity of air relative to the vehicle \( (V_a) \). In symbols, this is expressed as

\[
q \propto \varphi^{1/2} V_a^3.
\]

For a re-radiative thermal protection system, the skin temperature \( (T_s) \) is related to the heating rate approximately as

\[
T_s \propto (q)^{1/4}
\]

and, therefore,

\[
T_s \propto \varphi^{1/8} V_a^{3/4},
\]

approximately.

From preliminary results of entry aerodynamic heating analysis for the space shuttle, peak heating occurs in the 50- to 70-km altitude region. It is in this region that the largest relative variability of density occurs. Neglecting the effects of density variability on the velocity of the re-entry vehicle, which could be sizable for a high lift-to-drag (high L/D) vehicle, the effect of density on heating rate is given by

\[
\frac{\partial q}{q} = \frac{\partial \varphi}{2 \varphi}.
\]

The relative differences between the mean densities as given by the U. S. Supplemental Atmospheres at 60 km relative to the U. S. Standard 1962, are compared below.

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<th>Supplemental atmosphere</th>
<th>Relative to U. S. 1962 (per cent)</th>
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<tr>
<td>60N July</td>
<td>+25</td>
<td></td>
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<tr>
<td>45N July</td>
<td>+21</td>
<td></td>
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<tr>
<td>30N July</td>
<td>+12</td>
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<tr>
<td>15N Annual</td>
<td>-7</td>
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<td>U. S. Standard 1962</td>
<td>0</td>
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<td>30N January</td>
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<tr>
<td>45N January</td>
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<tr>
<td>60N January</td>
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From the above comparison, it is seen that the largest positive departures of density at 60-km altitude from the U. S. Standard Atmosphere occur over the summer polar region. During a major stratospheric warming event in winter over the North Polar region, the density at 60 km altitude may increase very significantly. This raises an interesting operational speculation: Suppose for a particular space mission there are options for the re-entry coordinates and aerodynamic heating is to be minimized, then the proper choice appears to be to make re-entry over the winter polar region, provided a stratospheric warming event is not in progress at the time, or to make a low altitude entry. Of course, the shuttle should be designed to minimize operational constraints, and every reasonable effort to do so will be made. Trajectory shaping has a large influence on aerodynamic heating. Even in the boost phase, a “hot” trajectory can be devised.

For re-radiative protection system, the cumulative heat is of lesser importance than for an ablative system. Thus, the extremes of density become more important than the structure of the density along the entry trajectory.

A comprehensive global thermodynamic model is needed. The desired model would consist of pressure, temperature, and density versus altitude, latitude, longitude, and time. Conceptually, this proposed model is referred to as a 4-D model for the dimensions or coordinates, latitude, altitude, longitude, and time. If we had an adequate series of synoptic charts at heights from sea level to 90 km, the data problem would be essentially solved. The presently available data consists of daily synoptic charts at selected standard pressure levels up to 10-mb level (~30 km) for the entire Northern Hemisphere. For the North American continent, synoptic charts to 0.4-mb level (~55 km) are available. We have two approaches under study to extend the presently available data base to higher altitudes. These approaches are 1) regression method based on inter-level correlation structure, and 2) a dynamic structure method.

From this data base, the vertical and horizontal structure of pressure, temperature, density, and geostrophic wind along any required vehicle trajectory could be determined. A number of statistics on these variables could also be summarized. Since this work is not com-
completed, and in order to meet the most urgent requirements for design values, extreme density profiles are being presented, and the use of available models are being recommended for preliminary design analysis. These models include the U. S. Standard Atmosphere, 1962; U. S. Standard Atmosphere Supplements, 1966; and the Cape Kennedy (PRA-63) Atmospheric Model.

6. Concluding remarks

Consistent and coordinated natural environment design criteria input to the space shuttle is one of the goals. The objective is to minimize difficulties in conducting comparative studies, while at the same time permitting trade-off studies on environmental influences. It is hoped that this will eliminate any deficiencies in the final design of the space shuttle due to oversight or lack of recognition of a natural environment parameter important to the operations.

Acknowledgments. This paper was based on the personal experiences of the authors and on the material contained in various references. Because of the large number of potential references, they are not listed; however, we wish to acknowledge the efforts of all investigators in the subject fields.

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news and notes

1969 Patterson Medal

Dr. G. Oscar Villeneuve, director of the Quebec Meteorological Service, received the Patterson Medal for 1969 at the annual meeting of the Canadian Meteorological Society in Winnipeg in June 1970. The Patterson Medal is awarded annually to the resident of Canada who has rendered distinguished service to meteorology, either over a period of time or through a recent outstanding achievement.

The presentation was made by C. C. Boughner, acting director of the Canadian Meteorological Service, who cited Dr. Villeneuve’s broad interest in advancing the science of meteorology rather than limiting his activities simply to the development of the Quebec Meteorological Service.

Dr. Villeneuve began his career in 1938 as a forest engineer in the Bureau of Meteorology of the Quebec Forest Service. After postgraduate studies at New York and Yale Universities, he was appointed director of the Bureau in 1944. He was the first professional meteorologist to study the forest climates of Quebec. He also analyzed forest fire seasons in relation to meteorological conditions, and was responsible for a greatly expanded network of meteorological stations in the province. He has taught climatology and meteorology at Laval University since 1947. His French textbook and the publication of more than 125 scientific papers and articles evidence the depth of his interests. He also founded “Feuillet Météorologique,” a monthly pamphlet providing information to climatological observers since 1950, and was an organizer of “La Société de Météorologie de Québec,” the first meteorological society of the French language in Canada. In 1965 he received a certificate of honor from “Le Ministere des Affaires Etrangeres de la Republique Francaise” recognizing his efforts and competence in applied meteorology.

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