BIOLOGY AND ENGINEERING OF SPACE AND PLANETARY LIFE SYSTEMS

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CONTENTS

PROGRAM SUMMARY

STIMULATION OF CARDIOVASCULAR ADAPTABILITY DURING PROLONGED SPACE EXPOSURE, 1-1

EXPERIMENTAL INVESTIGATIONS INTO THE PERFORMANCE OF A 20 CM HOLLOW CATHODE THRUSTER, 2-1

EXTINCTION OF INFRARED RADIATION DUE TO ATMOSPHERIC HAZE, 3-1
PROGRAM SUMMARY

This annual report summarizes the research program carried out under NASA Grant NGR06-002-038 in the year ending August 31, 1969. Detailed reports are included for three of the research projects supported under the Grant.

The following projects were supported under the Grant in the past year.

1. Stimulation of Cardiovascular Adaptability During Prolonged Space Exposure. Principal investigator, Dr. Harry A. Gorman, D.V.M., Professor of Veterinary Clinics and Surgery.

2. Experimental Investigations into the Performance of a 20 cm Hollow Cathode Thruster. Principal investigator, Mr. William R. Mickelsen, Professor of Mechanical Engineering.

3. Extinction of Infrared Radiation Due to Atmospheric Haze. Principal investigator, Dr. William Marlatt, Professor of Atmospheric Science.

4. Effect of Hypoxia on Erythropoiesis and Immune Response. Principal investigator, Dr. R. P. Tengerdy, Associate Professor of Microbiology Biochemistry.

5. Stimulus Programming Parameters in Human Information Processing. Principal investigator, Dr. John A. Modrick, Associate Professor of Psychology.

6. Studies of Circadian Rythmicity in Gonyaulax Polypedra. Principal investigator, Dr. R. W. Price, Associate Professor of Radiology and Radiation Biology.

The first three projects are reported in detail in subsequent sections. The second project is related to the general theme of the Grant through the potential future use of biowastes for propellant in electric rockets.
Research work done under the fourth project has been reported in the following publications.


Work on the last two projects was terminated by the resignations of Dr. Modrick and Dr. Price from the faculty of Colorado State University late in the calendar year 1968.

Research is proceeding in the third year of the Grant under the first three projects.

William R. Mickelsen, Professor Chairman, CSU Space Science and Technology Committee
STIMULATION OF CARDIOVASCULAR ADAPTABILITY
DURING PROLONGED SPACE EXPOSURE

by Harry A. Gorman*
Principal Investigator

PROBLEM

Astronauts returning to earth's gravity after long exposure to weightlessness have experienced circulatory problems including orthostatic hypotension, tachycardia, reduction in blood volume, lowered cardiovascular reflex response to shifts of blood to the extremities, and syncope or fainting. These same problems are shared by patients with long bed confinement when they are suddenly subjected to a standing upright position.

The causes of these conditions are complex, but in general they develop as a result of cardiovascular deconditioning due to reduced functional requirements of the circulatory system.

Development of a new technique for stimulating the cardiovascular system of sub-human primates is the object of this research. The results may be extrapolated to man under conditions similar to those of the primates.

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Intermittent venous pooling of blood in the distended lower vessels, triggers and stimulates the vascular reflex mechanisms of the cardiovascular system and can have significant benefits in keeping the circulatory system in top performance tone.

Pulsatile sleeves, fitting from the shoulder to the wrist on each arm and from the upper thigh to the ankle of each leg provide a sequential occluding of the venous return as a "rippling" action. The sleeves are actuated by compressed air through programmed valves to deliver from 40 to 90 mm Hg. pressure at 10 declining points along each arm and leg. The "ripple" effect, while pooling blood in the extremities, is a soothing massage and quite acceptable to the recipient.

The potential of these devices are evaluated by monitoring cardiovascular responses. The significance of the investigation is that it is directly aimed at the man in space program, and at the same time may prove to be of real therapeutic value to bed ridden patients with circulatory disease.

RESEARCH

As established in previous reports, the research of this project has been divided into two phases. The first phase encompassed the design, development, and fabrication of the sequential ripple sleeve system. Eight sub-human primates were fitted with the arm and leg sleeves and under light tranquilization, were subjected to lower extremity venous pooling.
The pulsator was modified from its original mechanical operating mode to one operated by sequential selinoids. A detailed description of the electronics was presented in the 1968 annual report and will be elaborated on in the final report. Numerous alterations have been made in the sleeve and still more are needed to establish a good fitting versatile cuffing for the "rippling" action. The latest version is displayed as (Fig. 1).

Monitoring of the physiologic parameters of the cardiovascular system have, in part, been described in earlier reports. Electrocardiograms continue to be taken by skin needle electrodes coupled to an amplifier and the signals are recorded on a Sanborn hot-stylus recorder. Leads I, II, III, AVF, AVL, and AVR are used to monitor heart changes during the venous pooling of blood in the arms and legs.

An indirect blood pressure measuring technique was modified for taking both systolic and diastolic pressures from the ventral corrygeal artery of the tail of the primates — thus freeing the arms and legs for the ripple sleeves. (Fig. 2&3).

In previous reports the techniques for determining cardiac output have been discussed. The use of radioisotopes, administered intravenously, to measure the ionizing radiation emitted during each cycle of the heart, was discarded because of radiation scatter nullifying any calculations. Electromagnetic flow meters (12 mm. & 14 mm. diameters) were purchased and are the
instruments employed for cardiac output measurements. They are surgically implanted on the ascending aorta, immediately adjacent to the heart. Measurements taken here can be calculated as total output minus that small amount of blood supplying the heart through the coronary arteries.

DATA ACQUISITION

Base lines for each of the parameters listed above are recorded in analog form and then the ripple sleeves are placed on the arms and legs and the system activated. Differences in parameter values are plotted in digital form and are the basis of evaluating the amount of challenge the active sleeves have on pooling blood and consequently challenging or exercising the heart and great vessels of the cardiovascular system.

Phase II

The second phase of the studies conducted under this project include the reverse action of the ripple sleeves that may prove to be a circulatory assist device. The rippling action, from the extremities toward the heart accelerates the venous blood return to the central circulation and decreases the volume of blood in the extremities. In cases of thrombophlebitis, edema, or poor venous return, this device shows much promise. It appears to be not only a circulatory assist approach but is a physical therapy application to aid the aged and those with problems of poor circulatory return.
Further investigations will be conducted during the ensuing year to evaluate the "pulsatile sleeve" as a practical method to stimulate the cardiovascular system to keep it in top performance. Further work will be done on the reverse action of the sleeve to develop its potential as a physical therapy device. Optimum application periods will be looked at as well as proper pressure gradients to be employed under each set of conditions warranting use of the device. Of special interest and needing more study is the development of a better sleeve. It is hoped that a very convenient yet efficient design may be forthcoming to permit simple application acceptable to both space and ground use.
Figure 1
Pulsator and Sleeve
Figure 2
Blood Pressure Measurement System
Figure 3
Indirect Blood Pressure Curve
EXPERIMENTAL INVESTIGATIONS

INTO THE PERFORMANCE

OF A 20 cm HOLLOW CATHODE THRUSTER

by Giuseppe Palumbo, Paul Wilbur
and Richard Vahrenkamp

INTRODUCTION

The 20 cm. hollow cathode mercury bombardment ion engine received from the Jet Propulsion Laboratory has been studied in the vacuum facility at Colorado State University. The research conducted has been concerned with performance mapping and the evaluation of various means of improving thruster performance. The report which follows includes the results of (1) magnetic field within the cathode pole piece; (2) hollow cathode propellant flow rate, and (3) effective baffle area. In addition, results of an investigation into the variation of thruster performance with lifetime is included.

Magnetic Field Within Cathode Pole Piece

Substitution of the hollow cathode for the oxide cathode in ion thrusters resulted in a significant increase in discharge losses.\(^1\) Masek\(^1\) has suggested this increase is due to an ion flux to the interior walls of the cathode pole piece, which can occur in the hollow cathode configuration. A magnetic field within the cathode discharge region (inside the inner cathode pole piece wall) was suggested\(^2\) as a means of reducing these losses by the following mechanism:


* It should be pointed out, however, that cathode power is not included as a discharge loss when oxide cathode data are presented, whereas this is automatically included in the hollow cathode data.
1. The magnetic field would cause electrons to gyrate around field lines, thereby preventing their migration to the walls.

2. Since ions would not be affected significantly by the magnetic field, the walls of the cathode discharge region would become positively charged.

3. The positively charged walls would repel the ion wall flux.

The work on reducing the ion wall flux began with an analysis to determine the magnetic field required to impede electron migration to the walls. King, et al., evaluating a hollow cathode thruster under conditions similar to those existing in the thruster being tested, states that the potential drop from the cathode to the plasma within the pole piece region is about 10 volts. This is the potential through which electrons from the cathode are accelerated, within the pole piece region, and it corresponds to an electron velocity of \(1.88 \times 10^6\) m/sec. Using this velocity, the electron gyro radius can be determined as a function of magnetic field from the equation \(r = \frac{mV}{eB}\) (Figure 1). Since the pole piece diameter is about 5 cm, and electron gyro radius less than 1 cm is needed, and Figure 1 shows this corresponds to a magnetic field between 10 and 100 gauss. The current \(i\) required to produce a magnetic field \(B\) inside a single layer solenoid with \(n\) turns per unit length is given by:

\[
i = \frac{1}{2} \frac{B}{\mu_0 n}
\]

The coil used in the experiments was constructed from #14 copper wire which could be wound in a single layer as tight as 420 turns/meter. The current given by the above equation for this turn density and the theoretical power consumed by the coil are also displayed on Figure 1.

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Figure 1

Cathode Pole Piece Magnet
Electron Gyro Radius
VRS
Magnetic Field Intensity
Current
Magnet Power

Electron Gyro Radius (cm)

B \( (\text{gauss} \times 10^3) \)

P \( (\text{watts} \times 10^3) \)

I \( (\text{amps} \times 10^{-1}) \)
Figure 2 is a photograph of the coil constructed for use in the 20 cm JPL thruster being studied. The supports shown, which also serve as insulators, are made of boron nitride, and the metal shield inside of the coil is made of nonmagnetic stainless steel and is connected so its potential can be controlled through an external circuit (Figure 3). The magnet current is supplied through an external power supply to the coil and then to the cathode pole piece and back to the power supply through the ground line. (Figure 3).
HOLLOW CATHODE DISCHARGE REGION SCHEMATIC

Figure 3

With the main magnetic field operating at a current of 1.5 amps and no current flow through the cathode field coil, the magnetic field pattern shown in Figure 4 was obtained. When the cathode field coil carrying 10 amps in such a direction as to aid the main field in the cathode pole piece was superimposed, the magnetic field configuration shown in Figure 5 was obtained. The data obtained with this magnetic configuration with or without the baffle in place, showed a universal degradation in performance (increase in discharge losses) with increases in cathode field coil current.
With the current in the cathode field coil flowing in such a direction as to oppose the main magnetic field in the cathode pole piece, the field line configuration in Figure 6 was obtained. Figure 7, which follows, shows the same configuration, without the baffle in place, to demonstrate the minor effect the baffle has on field line directions.

Performance data obtained with the magnetic field configuration, a flow rate of 5.3 gm/hr, the cathode field coil shield removed from the thruster and the baffle located flush with the end of the pole piece is presented in Figure 8. The data presented shows the effect of cathode magnetic field on the performance curves. These curves show the reduction of discharge losses is particularly significant at high utilizations. The data point which doesn't fit the $I_c = 5$ amp curve appears to be in error because of an incorrect beam current reading.

Figure 9 shows the variation of arc voltage with the current in the cathode field coil for various propellant utilizations. The effect of the magnetic field within the cathode discharge region is to increase the arc voltage. King, et al\textsuperscript{3}, points out that discharge voltage must lie within a relatively narrow range if optimum thruster performance is to be realized. Figures 8 and 9 tend to confirm this observation. The discharge losses (Figure 8) decrease with cathode magnetic field intensity, and the arc voltage increases with cathode field coil current (Figure 9), hence it may be that decreases in discharge losses can be linked directly to increases in arc voltage.

\section*{Discussion of Results}

The data suggests that the application of a cathode field opposing the main field resulted in a decrease in discharge losses whereas the application of a cathode field aiding the
The effect of magnetic field within the pole piece on discharge losses vrs utilization

$I_{\text{mag}} = 1.5 \text{ amps}$

$m_{\text{tot}} = 5.3 \text{ gm} \cdot \text{hr}$

---

**fig. 8 UTILIZATION**
Arc Voltage vs Cathode Field Coil Current

$I_{mag} = 1.5$ amps
$m_{tot} = 5.3$ gm/hr
Parameter - Utilization

fig. 9 Cathode Field Coil Current (amps)
main magnetic field resulted in an increase in discharge losses. Since the electrons should gyrate equally well regardless of the direction of the magnetic field, the above observation implies the improvements in performance that were observed were due to some effect other than controlling ion currents to the interior of the cathode pole piece as proposed originally. This deduction is supported by the fact that the improved performance was observed when the cathode field coil shield had been removed so the wall seen by the ions was essentially at ground potential.

The magnetic field configuration which resulted in improved performance (Figure 6) includes field lines which are largely radial in direction inside the pole piece in the region of the baffle. Assuming electrons emerging from the cathode are tied to field lines in that region, this suggests electrons will be ejected into the main discharge region with a radial velocity component that is large compared to the axial one. It is proposed that electrons ejected from the cathode with a largely radial velocity are more likely to produce ionizations than those electrons which reach the screen and are reflected to a collision with a thruster wall within a short period of time because of their larger axial velocity.

The resistance to electron flow in the radial direction is much greater than to axial electron flow, and one would therefore expect that rotation of the average electron velocity vector toward the radial direction would result in an increase in the discharge impedance and hence an increase in arc voltage. This is indeed observed as shown in Figure 9.

**Hollow Cathode Flowrate Studies**

The particle density within the pole piece region has been found to greatly affect thruster performance. A high density of neutrals tends to lower the impedance in the gap area between the baffle and pole piece, thus, affecting the discharge voltage. In order to observe the possible effects, a simple experiment of varying the hollow cathode flow at constant main flow was performed. Using the original thruster
fig. 10  Effect of HC Flow on discharge losses and discharge voltage
configuration (flat baffle), the hollow cathode flow was varied from about 2.3 g/hr to 0.65 g/hr. The effects of the flowrate on discharge losses and discharge voltage at 80% utilization are shown in Figure 10. As can be seen, the discharge voltage increases with decreasing particle density, until the impedance is higher because of the lower conductivity. The performance is better at the lower flowrates, suggesting that methods for increasing discharge voltage will reduce discharge losses. The adjustment of the flowrate is somewhat limited, however, due to instabilities in the discharge because of the low flowrate. A data point was also taken at a somewhat lower main flowrate in order to determine the general trend of the curves at various main flows.

It is interesting to note that if the ev/ion curve is extrapolated to zero flowrate, the losses are comparable with the losses at 80% utilization for the oxide cathode thruster. This may indicate that the ions produced in the hollow cathode region are lost due to wall and baffle recombination, whereas, all the ions produced in an oxide cathode discharge have a much higher probability of being accelerated. It must also be noted that in comparing the losses for the two types of cathodes, keeper power and main power were taken into account in the case of the hollow cathode, whereas, only main power was used in the oxide cathode calculation.

fig. 11 Conical Baffle Setup
Movable Conical Baffle Studies

In order to study the effects of baffle geometry and aperture area on the performance of the thruster, a movable conical baffle was installed as shown in Figure 11.

It has been suggested that the aperture area has an effect on the discharge voltage which must be above approximately 30 v. for improved thruster operation.³ It was also believed that the conical geometry would allow more ions to enter the main discharge region, rather than being contained in the pole piece region.

At a constant flowrate (hollow cathode and main), and a constant magnet current, data was recorded for various baffle positions. The results are shown in Figure 12 where discharge losses and discharge voltage are plotted for various baffle positions at 80% utilization. As can be seen, the losses increase with increasing gap area, while the discharge voltage decreases. Also, the losses decrease most rapidly in the region from 30.5 v to 31.5 v. This curve, therefore, suggests the importance of the discharge voltage on the performance of the thruster.

In order to study the effect of the conical geometry, data from Fig. 12 was compared with data from Fig. 11. By determining the points on both curves where the conditions are the same i.e., main and hollow cathode flow, aperture area, as well as utilization and magnet current, the discharge voltages and discharge losses could be compared. The flat baffle configurations incurred losses of 310 ev/ion at a voltage of 26.7 v, while the conical baffle incurred losses of 326 ev/ion at a voltage of ≈ 40 v. In the latter case, the higher voltage is believed to be due to the higher impedance due to the larger surface area of the cone. However, in this case, the higher voltage did not improve thruster performance. More experiments are being planned, and it is hoped that more accurate and more conclusive data can be obtained.
Magnet 1.5A
Main Flow 4.2 g/hr
HC Flow 2.4 g/hr
Utilization 80%

Figure 12 Effect of aperture area on discharge losses and discharge voltage
In the previous pages there is a description of the effects, on performance, of a magnetic field coil in the cathode pole piece and of a conical baffle. During these runs, it was noted that there was a significant difference in thruster performance between these data, at cathode field current zero, \( \frac{\alpha}{\mu} \) 250 ev/ion minimum and previous data taken, several months ago, without the cathode field coil and with a flat baffle at the end of the cathode pole piece \( \frac{\alpha}{\mu} \) 200 ev/ion minimum. The inaccuracy of the earlier data, due to poor meter calibration, was too small to account for these discrepancies and they were attributed to lifetime effect. Before the coil was taken out from the cathode region and the earlier condition reproduced in order to check the idea of time effect on the performance, the meters were calibrated again, possible leakage current eliminated by cleaning the insulators, controlling the wiring and the measurements improved by using a more adequate instrumentation. After the failure of these attempts, the cathode field coil was removed, the flat baffle was replaced and the earlier experimental condition reproduced. The total running period of the thruster, for the current sets of data, was approximately 90 hours at different main flow rates and mass utilization. The results of this investigation are summarized in Fig. 15, where two run at the same experimental condition and 84 hours apart are compared. The graph clearly indicate that there is an apparent change in performance with time, but the data are not enough to attribute such a difference to lifetime only.

CONCLUSION

Within the range of operation investigated an increase in arc voltage produced by (1) applying a magnetic field within the cathode pole piece region, (2) reducing hollow
cathode propellant flowrate, or (3) varying effective baffle area has been accompanied by a reduction in discharge losses (improvement in performance). It is believed that this performance improvement is effected through the increase in voltage through the following mechanism:

1. An increase in arc voltage results in an increased electron energy. The electron being accelerated primarily in the region between the cathode discharge and the main discharge where it is believed the increase in arc voltage is realized.

2. The higher electron energy corresponds to a higher ionization cross section as shown below.

![Graph showing Mercury ionization cross-sections](Fig. 16)

3. The higher ionization cross sections for electrons result in more effective utilization of electrons produced and hence lower discharge losses.

In the cathode magnetic field, cathode flow rate and different baffle configuration clearly indicated their effect on the performances; it is not so for the lifetime effect.

It is clear from the discussion already presented that the discharge losses appear to increase with lifetime, but the reason for this degradation in performance are not really known at the present time.
$I_m = 1.5\text{Amp}$

- $\bigcirc$ 8/20/69 6.5gr/hr
- $\triangle$ 5/7/69 6.4gr/hr

Fig 15.
EXTINCTION OF INFRARED RADIATION
DUE TO ATMOSPHERIC HAZE

by Yunn Pann and William Marlatt

SUMMARY

There are serious limitations to accurate evaluation of aircraft and satellite measurements of the upward flux of infrared radiation from the earth's surface. This has been due to the lack of knowledge concerning the value of surface emissivity and of transfer of the emitted radiation through the earth's atmosphere. The overall objective of this study is to further our understanding of the influence of surface emissivity and atmospheric transmissivity on the upward flux of infrared radiation. Major emphasis is placed on the role of haze extinction in the 8-14μ atmospheric transmission window.

Over the past several years a number of studies have been conducted at CSU under the objectives of this project in connection with other NASA research programs. These studies include measurement of a number of vertical profiles of upward flux of 8-14μ radiation over various natural surfaces and through different air masses. In obtaining these profiles both a model IT-2 and IT-3 radiometer (Barnes Engineering Company) and a 5 Channel MRIR radiometer loaned to Colorado State University by the NIMBUS project office of NASA-GSFC were employed.

The specific objective of this report (through September 1, 1969) is a comparison of measured upflux with that computed from a theoretical model of atmospheric radiation transfer.
The atmospheric transmission window between the water vapor band at 1596 cm\(^{-1}\) and the carbon dioxide band at 667 cm\(^{-1}\) (commonly referred to here as the 8-14\(\mu\) window) has been used extensively for estimation of cloud top and earth surface temperatures from both satellite and aircraft-borne sensors. The accuracy of these estimates has been somewhat limited due to (1) scarcity of information on surface emissivity and, (2) insufficient capability in evaluation of the transfer of the radiation through the earth's atmosphere. Because the wings of the continuum of both of these gases extend into this region (along with absorption bands of several minor gases) the 8-14\(\mu\) window is nowhere completely transparent—although the gaseous absorption becomes very small between 10 and 11\(\mu\). Aircraft and ground measurements over the Pawnee National Grasslands indicated that it is almost always necessary to correct radiometric measurements for atmospheric attenuation (Marlatt, 1967).

In addition to the correction requirements for gaseous absorption, a correction for the extinction of tropospheric aerosols has been suggested by Roach and Goody (1958), Deirmendjian (1960), and Marlatt (op. cit.). Several radiation profiles which were obtained in conjunction with the TIROS 7 and NIMBUS II underflights were made in situations of moderate haze. Other profiles were obtained under conditions of dry, clear skies. These flights were chosen as test cases for further evaluation under the present project program.

THE ATMOSPHERIC TRANSMISSION MODEL

From quantum mechanics we know that when energy is absorbed or emitted, one of three types of transitions—
electronic, atomic, or molecular--occurs. The absorption or emission of a discrete amount of radiation results in an absorption or emission along spectral lines rather than over broad bands. The cause of this phenomenon is to be found in the external fields to which the atoms and molecules are subjected during the process of radiation. In the absence of strong electrical or magnetic fields, the existence of spectral lines of finite width is mainly a result of 3 effects: (1) the disturbance due to collisions of molecules of the absorbing substance with molecules of non-absorbing gases, (2) the disturbance due to the mutual collisions of molecules of the absorbing substances and, (3) the Doppler effect resulting from the thermal motion of the molecules (Kondrat' yev, 1965) (Kunde, 1967).

Profiles of an emission line were estimated by considering the effect of collisions and Doppler effects under the assumption that, in the absorbing medium, the pressure and temperature remain constant over the entire beam (Kondrat' yev, op. cit.). In the actual atmosphere this assumption is only approximate if the atmospheric layers are thin (perhaps 10-25 mb). Because of the complicated structure of the real absorption bands occurring in the atmosphere, theoretical models can only be applied using a somewhat simplified structure.

Until the very recent past, all theoretical models of the structure of absorption bands may be placed in one of two categories. The first, suggested by Elsasser (1942) is characterized by equi-distant lines of equal intensity. The second, originally proposed by Goody (1952) assumes the distribution of both the intensities and positions of individual lines within bands are nearly random. In this second, the statistical model, the intensities and positions of the lines are determined by probability theory. Only recently has any information of significance concerning the exact position and intensity of specific lines for specific gases become available. These two models, with or without
measurement data, have been the basis for describing the transmission of radiation through the earth's atmosphere.

In the past few years, several computer programs have been developed for computation of radiative energy transfer through the atmosphere. Manabe and Möller (1961) developed a model to calculate the net terrestrial radiation for individual layers. Their transmission model uses a uniform transmission function for the entire infrared spectrum. Wark (1962) and Kunde (op. cit.) each developed models which calculate the upward flux of infrared radiation arriving at the top of the atmosphere at specific intervals of the spectrum. Cox and Kuhn (personal communication) also developed a model of this type. Davis and Viezee (1964) developed a model for computing infrared transmission through the atmosphere (upward, downward, and net) across the infrared portion of the electromagnetic spectrum from 4.65μ to 400μ in 25 wave number intervals. Each of these programs has been used to determine a theoretical amount of radiant energy arriving at the top of the atmosphere for comparison with satellite observations. Only the program of Davis and Viezee, however, provides the theoretical output of up, down, and net flux at the top of each atmospheric slab. In addition, their model includes the capability for varying the surface emissivity and the transmission angle and also includes the semi-transparent layers above or below the reference level.

Unfortunately the Davis-Viezee program was written in a computer language BALGOL. Nevertheless, our evaluation indicated that their program most closely fit the needs of the present study. Therefore, the Davis-Viezee computer program was translated into Fortran for use on IBM and CDC computers. Their theoretical model was then used to evaluate the aircraft measurements of upward radiation flux.

Translation of the Davis-Viezee computer program from BALGOL to Fortran was completed in early 1969. It had been hoped that the actual translation would be completed nearly a year earlier. Limitations in funding levels, however, presented continuous effort on this program translation.
EVALUATION OF THE COMPUTER MODEL

Before any comparison of the infrared radiation upflux computations with measured values from the aircraft program could be made, an evaluation of the effects of variations in the input variables on the program output was necessary. Variables requiring numerical values include surface temperature, surface emissivity, air profile temperature, air profile humidity, transmissivity and reflectivity of semi-transparent layers and instrument view angles. Since true values of most of these variables are difficult to ascertain, it becomes necessary to evaluate the contribution of each. Efforts during the period January-August 1969 have been directed toward this evaluation.

In this phase of the study, several cases corresponding to TIROS 7 overpasses over the Pawnee National Grasslands were used. Flights corresponding to TIROS 7 orbits number 1567, 2190, and 2263 were selected as representative for this purpose. Most calculations were restricted to a bandpass described by the transmission of the Barnes IT-3 radiometer filter. In a few cases, to describe a particular feature other bandpasses were used. For most cases the view angle was assumed to be in the vertical.
Fig. 1. Effect of surface emissivity on calculated radiation upflux. Emissivity $a=0.00$, $b=0.04$, $c=0.06$. 

236 °K

205 210 270 275 280 285 290

200

100

0

846 800 700 600 500 400 300 200

PRESSURE (mb)

TEMPERATURE (°K)
Variations in Surface Parameters

Without question the most significant factors affecting the upflux of infrared radiation are the temperature and emissivity of the active surface. The true surface temperature is normally not measured since the active surface may be one of many surfaces--tree canopies, grass and other plants, barren ground and water. The difficulty of in situ measurements of surface temperature has been reported earlier (Marlatt, op. cit.). For the test cases used in this evaluation both measurements of in situ temperature using miniature thermistor beads and radiative blackbody effective temperature using handheld radiometers were used. The radiometer temperature measurements included the effect of surface emissivity.

Since the Davis-Viezee computer model included an emissivity term in both surface emission and in the reflected downflux component in the total upflux value, it was possible to evaluate the total error contribution resulting from errors in surface emissivity assumptions. Figure 1 shows the effect of surface emissivity variations on the profile of upflux radiation. By maintaining a constant surface temperature and a constant downflux reaching the surface, a change of surface reflectivity decreased the total upflux arriving at the top of the atmosphere by an equivalent of 0.5-0.9°C. Comparable effects would be expected for an equivalent error in surface temperature.

Variation in Atmospheric Parameters

For the calculation of radiation transfer through the atmosphere, mean layer values of air temperature and specific humidity are required. For most instances, values of air temperature and water vapor content for the lowest layers of the atmosphere were obtained from the aircraft measurements. Above the aircraft flight altitude input data was obtained from the nearest radiosonde and above the radiosonde altitude, from the U. S. Standard Atmosphere. Input variables in the computation of radiation flux include air temperature, water vapor content and ozone. Ozone was added to the original
program as a semi-transparent layer with transmission values according to the U. S. Standard Atmosphere.

Figure 2 shows the effect of a $5^\circ$C error in air temperature throughout the atmospheric profile. Since most humidity data is recorded as relative humidity rather than specific humidity, errors in measurements in air temperature would result in even larger errors in humidity calculations. Table I shows the effect of errors in the measurement of atmospheric water vapor.

In Table 1 specific humidity "B" corresponds to humidity for profiles associated with TIROS 7 orbit 1567. "A" is for the same temperature profile, but the a 5% lower specific humidity and "C" is for the same temperature profile with a 5% greater specific humidity. It is apparent that these 5% deviations of specific humidities for a continental air mass do not materially effect upward fluxes of radiant energy in the 8-14$\mu$ bandpass.
Fig. 2. Effect of a 5% variation in air temperature profile on calculated radiation upflux. b is true value. a = 0.95b, c = 1.05b.
TABLE I

EFFECT OF A 5% DEVIATION IN SPECIFIC HUMIDITY ON RADIATION UPFLUX

<table>
<thead>
<tr>
<th>Pressure (mb)</th>
<th>Specific Humidity (g/kg)</th>
<th>Air Temp. (°K)</th>
<th>Upflux (T_BB) (°K)</th>
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<td>.58</td>
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<tr>
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<tr>
<td>846</td>
<td>3.04</td>
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Since ozone has a strong absorption band near the center of the 8-14 μ bandpass, it might be expected that this gas would affect the calculation of radiation upflux. Since the aircraft measurements are made well below the ozone layer, ozone would at best be a second order effect through reflected downflux and thus would be related only through surface emissivity. For emissivities >0.95 calculations indicated that upflux at the surface is not effected whatsoever by the presence of ozone in the high atmosphere.

The presence of clouds or dense haze layers has a marked effect upon radiation transfer. Figure 3 illustrates the presence of a cloud layer at 500 mb. In this example a transmissivity of 0.01 and a reflectivity of 0.00 is assumed.

PROGRAM LIMITATIONS

One serious limitation to the program tested is illustrated in Figure 1. It may be seen in this figure that the profiles of upflux increase with increasing air temperature near the top of the atmosphere even though the air temperature is very low and the transmissivity in this region is very high. The cause for this upflux recurve has not been determined at the time of this report.

A second program limitation concerns a semi-transparent layer. The assumption that the layer is of infinitesimal thickness is reasonable provided that the closest reference level for flux computation is either some distance above or below the level of the semi-transparent layer. This is a limiting control of the reference levels. Furthermore, since only one semi-transparent layer is permitted in the program, it is impossible to make comparisons between measured and calculated fluxes within a haze or cloud layer. It also prohibits a possibility of making comparisons in an atmosphere with several haze layers.

A third program limitation is the relative coarseness of transmissivity in bandpasses of 25 wave number width. The inclusion of new transmissivity data made available since this program was first written would permit reduction of the bandpass calculations to 5 wave numbers width.
Fig. 3. Effect of an infinitely thin semitransparent layer at 500 mb. Assumed transmissivity of 0.01 and reflectivity of 0.00.
DISCUSSIONS AND PLANS FOR FURTHER RESEARCH

Before continuing the analysis, it is necessary that the evaluation reported here be completed. Analysis of radiation transfer for seven flights over the Pawnee National Grassland and two flights over the Pacific Ocean will be computed and compared with the measured values. Data is available on the level and concentration of haze for the oceanic flights. If available Channel 2 data from NIMBUS II will be obtained for the comparison over the Pacific Ocean. Discussion with Cox and Davis indicates that new transfer models are now available. If these computer programs are compatible with our computer facilities, the new Cox program will be tested as well.
REFERENCES


Leadbbrand, S., 1967: Program FLUXR--a report on a computer application in the study of infrared flux radiation through the atmosphere. Fort Collins, Colorado State University, Department of Atmospheric Science, unpublished manuscript.


Shaw, R. W., 1966: Environmental errors in the use of the airborne radiation thermometer. M. A. Thesis, Department of Physics, University of Toronto.

