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A LATITUDINAL SURVEY OF THE HYDROXYL AIRGLOW EMISSIONS

Final Report

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INTRODUCTION

Under NASA Grant NGR 02-001-058, a multi-filtered, spatially scanning photometer system was placed aboard the NASA Convair 990 aircraft Galileo, and successfully operated through-out the NASA 1969 Auroral Expedition. The primary objective of this grant was to support the construction of equipment, its testing and operation during the NASA 1969 Auroral Expedition, and a cursory evaluation of the data. The analysis of the data is the subject of a proposal which was submitted to NASA in February, 1971. This final technical report describes both the instrumentation which was assembled for the experiment and the overall success of the airborne operational experiment, and includes a brief summary of some of the data which has been reviewed to date.

It should be noted that the instrumentation installed in the aircraft was used to carry out the University of Alaska programs under both NASA Grant NGR 02-001-058 as well as NASA Grant NGR 02-001-060.

The primary goals of the proposed airborne experiment were to acquire geographically widespread observational data on the emission intensities of hydroxyl (OH) and related airglow emission features, particularly at high latitudes. These data would then be analyzed for the purposes of ascertaining the relative importance of atmospheric dynamical processes, including those of a meteorological origin, as well as possible variations from the basic hydrogen-ozone reaction excitation mechanism to the production of hydroxyl airglow emissions. A concerted effort was also made to further establish the relationship between sudden increases in the intensity of the OH emissions from nominal polar airglow levels by the presence of active aurora, as noted by Brown and Belon (1969).

Instrumentation

The proposed experiment required data pertaining to both the spatial distribution and temporal variations of several airglow emission features. The modifications required to use an existing photometer system for these studies were mainly confined to the choice of a suitable detector for the near infrared and the signal detection and processing subsystems. From the outset there was considerable interest in obtaining and using an S-25 photocathode photomultiplier tube (PMT) which would have a certain prescribed level of sensitivity out to at least 9350A when moderately cooled, as opposed to a standard S-1(RCA 7102) PMT detector which would have required liquid nitrogen cooling.

An experimental S-25 PMT was ordered from IT&T(F-4075), with sensitivity specifications adequate for the planned observations. Production problems at IT&T left the final decision between the S-1 and the S-25 PMT open until early September 1969 when a low sensitivity S-25 IT&T (F-4085) was delivered on consignment for evaluation. A careful laboratory test bench comparison of the S-25 with the S-1 under simulated observational conditions proved that this tube would be adequate for the proposed observational program. Subsequently this PMT was integrated into the package and the pulse discrimination electronics adjusted accordingly. A second S-25 IT&T PMT, meeting initial specifications arrived at NASA Ames Research Center, Moffett Field, California just after the checkout flight and was installed, while the F-4085 was retained as a spare. Subsequent operation showed little difference in sensitivity between this S-25 PMT and that which had been thoroughly tested, however in view of its slightly higher sensitivity, as measured at the factory, it was used throughout the flights and upon completion of the expedition, the first tube (F-4085) was returned to IT&T.

From a knowledge of the operational characteristics of the basic optical system when used at shorter wavelengths for other types of auroral and airglow studies, a decision was made to use pulse counting signal detection techniques. In order to retain flexibility under a variety of possible observational conditions, and also to interface smoothly with the existing analog recording instrumentation, the raw pulse data were converted to analog voltage levels. These were then passed into four separate amplifiers that resulted in four separate decades of signal level which were available simultaneously, ranging from 0 - 200 cps to 0 - 200,000 cps. In operation, pulse pile up occurred at approximately 40,000 cps. A manual multipole switch placed a load resistor chain with these same four amplifiers across the anode if analog detection were desired over the range of 10^{-7} to 10^{-4} amperes full scale. This feature was used successfully for a short period during a day to night transitional flight which occurred during passage from Ft. Churchill to Bodø, Norway.

The remaining modifications were minor, consisting for the most part of installing a 1° resolution shaft encoder assembly on the optical field of view scanning system, reprogramming the filter wheel movement circuitry for positive filter identification and stop-motion movement, and general construction for aircraft mounting. The full specifications of the instrument follow:

The filtered photometer system consisted of a single optical system whose field of view was spatially scanned in elevation angle through a "60° window" of the aircraft and in which narrow band interference filters were programmed to move sequentially into the optical path.

Optics: The objective was an achromat with an entrance aperture of 4.75" and focal length of 15.6" which was followed by a Ross Corrector inserted 11.75" behind objective to accomodate 2.8" diameter interference filters.

Instantaneous Field of View: 6.0 x 10^{-5} steridians (0.5° circular)

Effective spatial regions viewed: Elevation angle scans were made from a zenith angle of 50° to the zenith at right angles to the flight path of aircraft.

Field of View-Scanning Rate:

Mode 1 - stationary or manual set point control to within 1° accuracy, with a shaft encoder readout on the operator's panel.

Mode 2 - motor driven with set point speed control

a. set-point variable, 0°/sec to 450°/sec.

b. discrete, 6°, 12°, 30°, 60°, 150°, 300°, 450°/sec.

Filter wheel:

Up to eight separate interference filters were mounted on a programmable wheel with an access plate which permitted changing interference filters during flight conditions if necessary. A discrete eight level electronic code for positive filter identification was displayed on the front panel for the operator and recorded for analysis.

Filter Change Rates:

Mode 1 - manual-pushbutton CW or CCW

Mode 2 - internal timer which permitted observing time with a given filter of 1, 10 or 25 seconds.

Mode 3 - Filter change initiated by pulse derived from elevation scanning optical assembly.

The minimum time between filters was 0.12 sec.

Signal detection:

Pulse counting followed by digital to analog conversion using a simple R-C integrator. The output of the integrator being fed to four separate amplifiers resulting in four discrete decades of output signal corresponding to:

$0 - 2 \times 10^2$ cps

$0 - 2 \times 10^3$ cps

$0 - 2 \times 10^4$ cps

$0 - 2 \times 10^5$ cps

with a basic time constant of the integrator as 180 Hz.

Detector:

IT&T F-4075 (S/N 096904) S-25 photocathode, 0.2" diameter effective photocathode, 16 dynodes, operated at 2100 vdc.

Detector Cooler:

Products for Research model TE-102S, operated at set-point of -10°C with a stability of 0.1°C.

Recording:

Analog output signals were recorded on seven channels of one of the two available NASA CP 100 Ampex 14 track recorders. These were;

Channel	Data	Level
1	$0 - 2 \times 10^2$ cps	-10 to + 10 volts
2	$0 - 2 \times 10^3$ cps	-10 to + 10 volts
3	$0 - 2 \times 10^4$ cps	-10 to + 10 volts
4	$0 - 2 \times 10^5$ cps	-10 to + 10 volts
5	Elevation angle position	0 to + 10 volts
6	8 level filter identification	0 to + 10 volts
7	IRIG B time code	(supplied by NASA)

In addition, a two channel Sanborn chart recorder was installed in the equipment rack with multipole data access switches, so that the performance of the system could be monitored and checked in flight.

Operation

The airborne operation of the instrumentation built by the University of Alaska for this work was remarkably trouble free and stable throughout the expedition, and at no time were data lost due to an instrumentation failure. Post flight analysis of the data has revealed a few occasions during which the NASA CP 100 tape recorder failed to function properly, notably during the ferry flight to Ft. Churchill, Canada from Moffett Field, California Fortunately the monitoring data acquired with the supplemental two channel Sanborn recorder presents good coverage so that the information gained during this flight is not totally lost.

A summary of the operation of the instrument is listed in Table I. In Table II, the channel wavelengths are listed along with the emission feature that was observed.

TABLE I

Operation Resume

1969 Date UT	Flight	Mode of Operation Scanning	Mode of Operation Zenith	Time Interval U.T.	Recording Mode Tape	Recording Mode Chart	Channel Wavelength 1	2	3	4	5	6	7	8
	1	✓	✓	Test Flight		✓								
Nov.24	2		✓	0806 1231		✓	4278	5893	5577	6300	8630	7250	8345	9350
Nov.26	3		✓	0042 0133	✓	✓	4278	7250	4861	6772	8911	8630	8345	9350
		✓		0133 0239	✓	✓								
			✓	0239 0307	✓	✓								
		✓		0307 0319	✓	✓								
			✓	0319 0437	✓	✓								
		✓		0437 0611	✓	✓								
Nov.27	4		✓	0033 0225	✓	✓	4278	7250	6772	8911	8630	8345	9550	4861
		✓		0225 0230	✓	✓								
			✓	0230 0450	✓	✓								
		✓		0450 0532	✓	✓								
Nov.29	5		✓	0225 0620	✓	✓	4278	7250	6772	8911	8630	8345	9350	4861
Dec. 3	6		✓	0513 0536	✓	✓	4278	7250	6772	8911	8630	8345	9350	4861
		✓		0536 1025		✓								
Dec. 4	7		✓	0450 0930	✓	✓	4278	7250	6772	8911	8630	8345	9350	4861
	8		✓	0610 0640	✓	✓								
Dec. 5		✓		0640 0756	✓	✓								
			✓	0756 0850	✓	✓								
		✓		0850 1000	✓	✓								
			✓	1000 1127	✓	✓								
Dec. 7	9		✓	0515 0600	✓	✓	4278	7250	6772	8911	8630	8345	9350	4861
		✓		0600 0744	✓	✓								
			✓	0744 1016	✓	✓								
Dec. 8	10			0745 1245		✓	4278	7250	6772	8911	8630	8345	9350	4861
Dec.11	11			1850 2135	✓	✓	4278	7250	6772	8911	8630	8345	9350	4861
		✓		2135 2230	✓	✓								
Dec.13	12	✓		0630 1130	✓	✓	5577	4278	5000	4861	6300	8911	8345	8630
Dec.14	13	✓		0530 1030	✓	✓	5577	4278	5000	4861	6300	8911	8345	8630
Dec.16	14		✓	0120 0203	✓	✓	5577	4278	5000	4861	6300	8911	8345	8630
		✓		0203 0550	✓	✓								
			✓	0550 0553	✓	✓								
		✓		0553 0804	✓	✓								
Dec.18	15	✓		0817 0933	✓	✓	5577	4278	9350	4861	6300	8911	8345	8630
			✓	0933 1028	✓	✓								
		✓		1028 1426	✓	✓								

TABLE II

Wavelength in Angstroms	Emission Airglow	Feature Auroral
4278	Background	1 NG (N_2)
4861	Background	H_β
5577	[OI]	[OI]
5893	Na	Nz/O_2*
6300	[OI]	[OI]
6772	Background/OH*	1PG (N_2)
7250	OH (8-3)	Meinel N_2^+
8345	OH (6-2)	Meinel N_2^+/OH*
8645	O_2 (0-1)	O_2/1PG* (N_2)
8911	OH (7-3)	1PG (N_2)
9350	OH (8-4)	OH

* Blend

A Brief Summary of the Data Reviewed to Date

We have been fortunate to have Mr. Robert Henderson, who is attending the University of Alaska on a NASA Fellowship, involved in the analysis of some of the data acquired during the expedition. He is now completing his analysis of the cross latitudinal, auroral zone and polar cap airglow levels of OH and 0_2 observed during seven of the fifteen flights, during which auroral activity was the lowest. Further analysis has been hindered by lack of funding and the recent move of all data processing instrumentation to the new Geophysical Institute building at the University of Alaska.

Briefly, from Mr. Henderson's work, we have been unable to find any qualitative or quantative difference in the emission intensities of OH which can be related to latitude or longitude effects. During these seven flights the diurnal variations that were observed were very similar in nature to those which have been reported for low latitude observations. In total, the worldwide undisturbed airglow OH emissions seem surprisingly stable with little evidence to suggest that any peculiar variations might occur at high latitude, although it should be recognized that these are the first such observations and they are limited to a very short seasonal period during November and December future extension of this work over a larger period may reveal gross changes.

The initial selection of data covering relatively undisturbed periods at high latitude included, as it later developed, at least one instance of a marked increase in the OH emission intensities. During flight #14 which originated in Bodø, Norway, the aircraft passed through the auroral zone into the polar cap and out again, terminating at Ft. Churchill, Canada. In reviewing the flight plan it was noted that the aircraft took off early in the morning sector (local time) and advanced in local time gradually overtaking the midnight sector near Ft. Churchill. The OH emission intensities showed a steady rise starting near the mid-point of the flight, when the aircraft was over Greenland and within the polar cap. The intensity enhancement was nearly a factor of two and seems clearly related to the meteorology of the upper atmosphere.

Suggestions for future work

The instrumentation designed and built by the University of Alaska operated reliably throughout the expedition and was successful in that observational data which had not previously been available was acquired from both low and high latitudes. This was due in part to the design concept employed, the prior experience of Dr. Romick aboard the NASA 990 aircraft and to the technical and operational support provided by the personnel of the Airborne Science Office of NASA, Ames Research Center.

The work which was initiated and carried out under this NASA Grant is one of the first attempts to document geographically large scale OH airglow phenomena on a consistent basis. The capability to observe OH airglow emissions at high latitude in close proximity to aurora, which has been firmly established through the work of Brown and Belon (1969) and more recently by Harrison (1970), should now permit a truly global picture of OH airglow phenomena to emerge. The importance of such studies are two-fold; initially it is well recognized that auroral zone and polar data do not exist and that they form a significant part of the overall phenomenology of OH airglow, with implications for polar upper atmospheric meteorological processes, and second, the spectacular perturbation of the nominally airglow emissions, such as OH and O_2 $^1\Delta g$ by the aurora have implications for many current and future studies of the photo and ion chemistry of the D and E regions of the earth's upper atmosphere.

Therefore we can recommend that whenever possible, hydroxyl airglow emissions should be studied from an airborne platform with these purposes in mind. As spectral discrimination of the aurora from the airglow has been achieved we can now also suggest that should funding be available, these studies should be expanded to cover the measurement of the effective rotational temperatures of OH as well as the diurnal, seasonal, and latitudinal variations. The extension of this work would also permit better coverage of one of the main comparative points between present theoretical studies and observations, that is, the variation in the intensities and effective rotational temperatures, which occur in twilights as a result of the changing height of the effective emitting layers, as well as the transitions from dayglow to purely nightglow excitation mechanisms.

In reviewing this particular experiment, there is also one unique aspect which these experimentors feels merits attention with respect to many types of future auroral expedition experiments, and that is the capability to scan the optical system spatially.

This capability greatly aids subsequent data analysis in terms of discriminating between various spectral, temporal and spatial variations during the periods when the observations were made.

During the course of the expedition, with the low level of auroral activity encountered, little data would have been obtained from fixed field of view observations, relating to the dynamic enhancements of OH which are typically associated with relatively bright auroral forms.

In general, the magnitude and reliability of data acquired with nearly any optical instrument used in auroral and airglow studies is greatly enhanced by a pointing capability.

While this is not always efficiently possible with any given experiment and instrument, it is deemed in general to be a desirable factor.

Other aspects of the total expedition seem worthy of special recommendation and acknowledgement. The importance of planning and carrying out a coordinated inter-calibration should not be overlooked in future expeditions, particularly when such a relatively diverse group of auroral investigators meet. In addition, the Dr. William Fastie "hot seat" procedure of requesting inflight cross checks during actual observations shakes many a "gremlin" from the calculations, as witnessed during these flights.

The second aspect deemed worthy of favorable mention is the inclusion of a low light level real time imaging system, wide field of view experiment whose monitors are placed throughout the aircraft interior for the various other experimentors to view. In the active semi-lit environment of the aircraft cabin, where most overhead hatches are filled with instrumentation, these monitors served an invaluable purpose in establishing the operational procedures or program changes necessary to acquire high quality data for various experiments during the expedition.

REFERENCES

Brown, N. B. and A. E. Belon, Trans-Amer. Geophys. Union 50, 258, 1969.

Harrison, A. W., J. Geophys. Res., 75, 1330, 1970.