UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER AFGL-TR-81-0154	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) WINTER AND SUMMER MEASUREMENTS OF EUROPEAN VERY LOW ALTITUDE VOLUME SCATTERING COEFFICIENTS		5. TYPE OF REPORT & PERIOD COVERED Scientific - Interim Scientific Report No. 15
		6. PERFORMING ORG. REPORT NUMBER SIO Ref. 81-26
7. AUTHOR(s) Richard W. Johnson		8. CONTRACT OR GRANT NUMBER(s) F19628-78-C-0200
9. PERFORMING ORGANIZATION NAME AND ADDRESS University of California, San Diego Visibility Laboratory La Jolla, California 92093		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62101F 7670-14-01
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Geophysics Laboratory Hanscom AFB, Massachusetts 01731 Contract Monitor: Major John D. Mill/OPA		12. REPORT DATE June 1981
		13. NUMBER OF PAGES 24
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Atmospheric Scattering Coefficient
Surface Visibility
Slant Path Contrast Transmittance

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report presents measurements of atmospheric volume scattering coefficients collected during twenty-nine low altitude flights made during the Winter and Summer seasons of 1978 at four different European locations. The measurements were conducted during an instrumented aircraft's final approach and landing at its staging airbase. The measurements were made using a pseudo-photopic spectral response and thus are suitable for comparison with data associated with standard visual determinations of airfield visibility.

20. ABSTRACT continued:

The data illustrate that in twenty-six of twenty-nine cases, there was little or no significant variation in the value of scattering coefficient as the aircraft approached the surface from an altitude of several hundred meters.

AFGL-TR-81-0154

SIO Ref. 81-26

WINTER AND SUMMER MEASUREMENTS OF EUROPEAN VERY LOW ALTITUDE VOLUME SCATTERING COEFFICIENTS

Richard W. Johnson

Visibility Laboratory
University of California, San Diego
Scripps Institution of Oceanography
La Jolla, California 92093

Approved:

Roswell W. Austin, Director
Visibility Laboratory

Approved:

William A. Nierenberg, Director
Scripps Institution of Oceanography

CONTRACT NO. F19628-78-C-0200
Project No. 7670
Task No. 7670-14
Work Unit No. 7670-14-01

Scientific Report No. 15
June 1981

Contract Monitor
Major John D. Mill, Atmospheric Optics Branch, Optical Physics Division

Prepared for

AIR FORCE GEOPHYSICS LABORATORY
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
HANSCOM AFB, MASSACHUSETTS 01731

SUMMARY

This report, which describes portions of the Visibility Laboratory's Project OPAQUE effort, was prepared under AFGL Contract F19628-78-C-0200. It contains a presentation of 29 low altitude scattering coefficient profiles and related meteorological data that were measured during the Winter and Summer seasons of 1978 at four different geographical locations. The measurements were conducted during an instrumented aircraft's approach and landing at four of the staging bases associated with the overall OPAQUE program, Johnson *et al.* (1979).

The nephelometer measurements of total volume scattering coefficient which are presented in this report were made using a pseudo-photopic spectral response having a mean wavelength of 557nm, and are thus suitable for comparison with data associated with standard visual determinations of airfield visibility. The temperature and dewpoint temperature measurements were made using an AN/AMQ-17 aerograph and a Cambridge Model 137-C3 Aircraft Hygrometer System. Measurements of horizon and terrain luminances which were also made during these aircraft descents are not included in this report, but are available in the Visibility Laboratory's basic data base should their subsequent analysis become desireable.

The reported data illustrate that in twenty-six out of twenty-nine cases, there was little or no significant variation in the photopic scattering coefficient as one approaches the surface from an altitude of several hundred meters. Thus modelling approximations of low altitude haze properties based upon near surface measurements are in general appropriate for the range of meteorological conditions extant during these flights.

TABLE OF CONTENTS

LIST OF TABLES AND ILLUSTRATIONS

WINTER AND SUMMER MEASUREMENTS OF EUROPEAN VERY LOW ALTITUDE VOLUME SCATTERING COEFFICIENTS

Richard W. Johnson

1. INTRODUCTION

In the increasingly sophisticated world of electro-optical detection, search, and guidance, the requirement for establishing and predicting atmospheric influences on system performance continues to develop as a primary operational necessity. It is in support of this general context that the Visibility Laboratory in cooperation with, and under the sponsorship of the Air Force Geophysics Laboratory has maintained an extensive program of airborne optical and meteorological measurements. In recent years this program has been conducted as an independent but cooperative effort [Johnson *et al.* (1979)] in conjunction with the NATO program OPAQUE (Optical Atmospheric Quantities in Europe), Fenn (1978). During the two year interval spanning the years 1977 and 1978, over 80 missions were flown documenting the vertical structure of the visible spectrum total volume scattering coefficient in the lower troposphere. Since a thorough awareness of this vertical structure is essential to the prediction of atmospheric influences on contrast transmittance through this regime, these data have been presented in a series of technical reports, the most recent of which is entitled "Airborne Measurements of Atmospheric Volume Scattering Coefficients in Northern Europe, Summer 1978", Johnson and Gordon (1980).

The optimum use of the experimental data presented in reports such as Johnson and Gordon (1980) is surely to establish the baseline assessment of those optical characteristics most influencing slant path contrast transmittance, and to develop from these assessments realistic predictive models. An initial effort in this model development, using both surface and profile data from the OPAQUE program is discussed in Johnson *et al.* (1979), and the further application of these data to contrast transmittance modelling is illustrated by Hering (1981).

A necessary but unfortunate artifact of the data presented in the report series referred to above, Johnson and Gordon (1980) etc. is that the measurements were always terminated at some significant altitude above ground level. A necessary condition imposed by the safety of flight regulations which apply to a civil air space, and an unfortunate condition due to the extreme sensitivity of slant path contrast transmittances to variations in the near surface haze conditions. Thus, even though the structure of the atmospheric scattering coefficient profile has been well documented within the altitude regime between 6 km and about 1 km above ground level, the true character of the near surface layer has been relatively undetermined. Several methods of extrapolation from the lowest measured data value have been used to identify the most probable values of scattering coefficient within this region, as have intermittent instances of interpolation between airborne and surface measurements when both were available. Obviously, neither of these techniques addresses the determination of the shape of the profile within the first kilometer above the surface. Consequently, there exists a significant degree of uncertainty in how one should properly define this altitude regime when attempting to calculate or predict its optical properties. This uncertainty is particularly troublesome when one addresses operational scenarios involving low flying systems whose mission depends upon the adequate performance of its electro-optical devices.

The data contained in this report are intended to reduce, at least in part, the uncertainties in the structure of the near surface scattering coefficient profile. These data, identified in Table 1.1, represent measurements made following each experimental data flight during the instrumented aircraft's approach and landing sequences. Thus the measurements were made in the specific region of interest, *i.e.* between the approach pattern altitude of approximately 1200 ft. and the surface, and can be used directly to identify the optical characteristics of this tactically critical transition zone. The flights indicated in Table 1.1 are all from the OPAQUE IV and V deployments, Johnson and Gordon 1979 and 1980, and thus represent only a sub-set of the total available data base. A second report, currently in preparation, will present similar data for the predominantly Spring and Fall time periods.

Table 1.1. Flight Identification Data

Aerodrome Identification	Flight No.	Flight Date	Landing Time (GMT)
Sigonella, Sicily 37°24'N 14°55'E 24m MSL	432 433 434	03 Feb 78 17 Feb 78 18 Feb 78	150001 130853 140005
	460 461 462 463	02 Aug 78 03 Aug 78 05 Aug 78 07 Aug 78	154910 124724 132230 134112
Wunstorf, Germany 52°28'N 09°25'E 57m MSL	451 452 454 456	22 Mar 78 23 Mar 78 28 Mar 78 31 Mar 78	144535 160830 141440 163702
	465 466 468 469	14 Aug 78 15 Aug 78 21 Aug 78 22 Aug 78	153657 134150 131440 160952
Memmingen, Germany 47°59'N 10°13'E 634m MSL	435 436 437 439	23 Feb 78 23 Feb 78 27 Feb 78 01 Mar 78	104356 152402 135823 145643
	471 473	11 Sep 78 11 Sep 78	092904 163609
Mildenhall, England 52°22'N 00°29'E 10m MSL	443 444 445 447 448	09 Mar 78 11 Mar 78 13 Mar 78 15 Mar 78 17 Mar 78	155711 162448 132659 150413 144958
	475 476 477	15 Sep 78 16 Sep 78 18 Sep 78	174646 153834 152524

Note: GMT times are indicated in Hours-Minutes-Seconds.

2. PROCEDURES & INSTRUMENTATION

The general flight sequences conducted during the OPAQUE measurement program have been reported in several preceding reports as noted in bottom row entries of Table 2.1. In these earlier reports, measurements of atmospheric volume scattering coefficient and natural irradiance levels were presented for a broad variety of geographical and seasonal conditions. The general locale for these data missions is illustrated in Fig. 2-1 which has been abstracted from Johnson *et al.* (1979). The aerodromes at which the approach data were measured are indicated by the symbol, ★.

The instrumentation used during these flight episodes has been described adequately in the previously referenced reports [Johnson and Gordon (1980), etc.] and will not be further elaborated upon herein. Suffice it to say that the entire instrument system was mounted on an Air Force C-130 aircraft and included, but was not limited to, the following listed items:

a. A multi-channel, multi-spectral nephelometer for the measurement of atmospheric total volume scattering coefficient and directional scattering functions,

b. multi-spectral scanning radiometers for the measurement of sky and terrain radiances,

c. a multi-spectral, two channel flat plate irradiometer for the measurement of upwelling and downwelling irradiance levels, and

d. meteorological transducers for the measurement of ambient temperature, dewpoint temperature and atmospheric pressure.

A special measurement sequence was associated with most flights discussed in these earlier reports, but its resultant data were not included as part of the standard flight package, nor included in those reports. These specialized data resulted from having the airborne optical, meteorological, and data logging instrumentation operational during the aircraft's landing approach and touchdown. Thus, since the aircraft was staging out of an airfield generally remote from the standard OPAQUE flight tracks shown in Fig. 2-1, two separate and independent data sets were collected during most missions. The

Table 2.1. Geographical and Seasonal Distribution of Low Altitude Scattering Coefficient Profiles

Aerodrome Locations (see Fig. 2-1)	Attempted Low Altitude Data Sequences				
	Spring, 1976	Fall, 1976	Summer 1977 & 1978	Winter 1978	Totals
Sigonella, Sicily	0	0	4*	4*	8
Lorient, France	0	4	3	0	7
Memmingen, Germany	0	0	3*	6*	9
Wunstorf, Germany	3	5	13*	4*	25
Soesterberg, Netherlands	1	0	0	0	1
Mildenhall, England	4	0	3*	6*	13
Vaerlose, Denmark	2	1	4	0	7
Totals	10	10	30	20	70
Related Data Reports	AFGL-TR-77-0078	AFGL-TR-77-0239	AFGL-TR-78-0168 AFGL-TR-80-0207	AFGL-TR-79-0159	AFGL-TR-79-0285

*Asterisk indicates those sub-sets from which the data in this report were chosen.

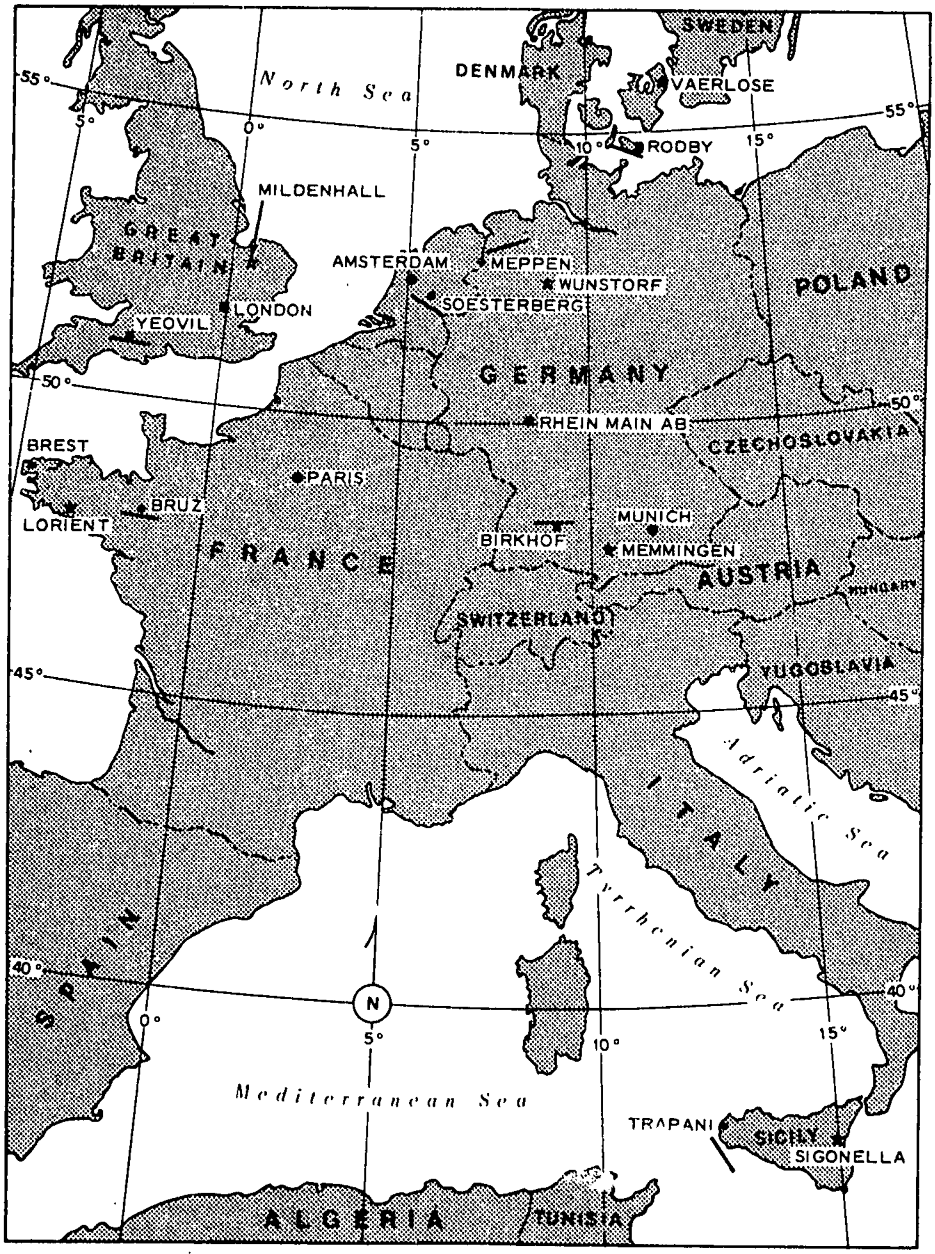


Fig. 2-1. Typical OPAQUE Flight Tracks.

first was the rather extensive, multi-spectral set of measurements made along the indicated tracks between 6.0 and 0.5 kilometers in altitude, and the second was the smaller more selective set made at the local staging base between about 0.7 and 0.0 kilometers. This second set of measurements, made only in the photopic spectral band, is nominally referred to as the APPROACH data.

There were several special considerations imposed during the collection of the APPROACH measurements which distinguish these data from the larger sets previously reported. In general they were as follows:

1. Measurements were made in only one spectral band. During the APPROACH descent from approximately 1200 ft. AGL to the surface, the structural character of the scattering coefficient profile was the datum most desired. Thus the integrating nephelometer was pre-set to make continuous measurements of the photopic $(\bar{\lambda} = 557\text{nm})$ total scattering coefficient throughout the descent. By not switching optical filters, all measurements were accomplished with the optimum spatial resolution.

2. Measurements were made with pre-set, static optical configurations. This consideration was also imposed

to eliminate unnecessary time sharing sequences and thus optimize the detection of profile variations during the relatively short descent episodes. Thus the nephelometer was pre-set to measure total scattering coefficient only without cycling through the directional channels; the scanning radiometers were pre-set to stare at the sky and terrain directly ahead of the aircraft, approximately 5° above and 5° below the local horizon; and the dual channel irradiometer was pre-set to measure total downwelling irradiance throughout the descent.

3. Data logging began shortly before the initiation of the aircraft's final descent for landing and continued throughout the descent and actual aircraft touchdown on the runway. Some editing has been required to eliminate spurious pre-descent and post-landing data which were adversely influenced by abnormal aircraft attitudes during initial line up and prop reversal influences during roll-out.

Post deployment data processing of these data has been handled in a manner similar to that described in Johnson and Gordon (1979). Calibration data for each deployment set is the same as was used for the parent data sets as referenced in each of the Related Data Report entries of Table 2.1. Readers are referred to these more detailed reports for supplementary background information where required.

3. WEATHER SUMMARY

The weather conditions existing during each of the flight episodes from which the APPROACH profiles have been extracted are discussed in detail in Johnson and Gordon, 1979 and 1980. These parent reports include data from daily surface and 500 millibar charts, surface observations, pilot reports, vertical cross sections and radiosonde launches. The bulk of these data were provided by the U.S. Air Force Environmental Technical Applications Center (USAF/ETAC) at Scott Air Force Base, and the National Oceanographic and Atmospheric Administration via the National Climatic Center in Asheville, North Carolina.

Comparisons between the C-130 and RAOB airborne measurements of temperature, dewpoint temperature, and the derived values of relative humidity for each of the winter and summer flights preceding these APPROACH episodes have been made in the parent reports referenced above. However, several additional comparisons are summarized herein which relate more directly to the actual landing circumstances.

Measured values of temperature (t), dewpoint temperature (dp), and atmospheric pressure (p), that were recorded at the exact moment of landing touchdown have been compared with the equivalent values reported by the host aerodrome for eighteen of the flights reported in Section 4. These flights were those for which the flight dynamics data permitted a specific and unambiguous determination of the exact instant of landing. Those flights for which the landing time was for any reason non-specific were not included in the comparison, even though their data might in fact be suitable in all other respects. These comparisons are listed in Table 3.1. In all cases the differences, Δt, Δdp and Δp, represent the aerodrome measurement minus the C-130 measurement.

The data summarized in Table 3.1 indicate that the airborne and aerodrome measurements were on the average in reasonable agreement. The temperature data indicate a systematic difference of about 1°C between the C-130 and aerodrome measurements, however the dewpoint and pressure measurements indicate no similar systematic offset.

Table 3.1 Comparison of Aerodrome & C-130 Data Differences (Measurements During Landing)

Aerodrome	Flight Number	Temperature Δt (°C)	Dew Point Δdp (°C)	Pressure Δp (mb)
Sigonella	432	+1.9	-1.8	-2
	433	+0.2	+0.5	-2
	461	+2.1	+4.4	-4
	463	+1.0	+2.7	-1
Wunstorf	451	+0.9	-3.4	+1
	454	+4.0	+1.1	-5
	468	+2.6	-1.5	-7
	469	+3.0	-2.5	-1
Memmingen	435	+0.2	-1.6	+4
	436	+0.3	-1.7	+5
	437	+3.0	-1.1	+1
	473	+1.9	+3.9	+2
Mildenhall	443	+1.4	+0.6	-2
	444	+1.5	+1.1	-4
	445	+0.9	-1.4	-6
	475	+0.2	-0.5	-5
	476	+1.1	-2.0	+3
	477	+1.2	-1.4	-1
Overall Average	18 Flights	+1.5	-0.2	-1.3

Note:

1. Δt is positive for all 18 flights implying systematically low measurement by the C-130 system.
2. Δdp & Δp reflect both positive and negative values intermixed throughout the 18 flights.

Since the staging aerodromes for most of these flights were generally remote from the primary data tracks, selected supplemental weather data related specifically to the APPROACH site have been included herein. Short summaries of the meteorological observations taken at the staging aerodrome, at or near the time of landing are presented in Table 3.2. A glossary of the most often used symbols is included in Appendix A for the reader's convenience. All data were reported in Greenwich Civil Time (GCT), which is equivalent to Greenwich Mean Time (GMT), the terminology used in Table 3.2.

Table 3.2a Sigonella, Sicily Standard Meteorological Data Sheet Lat. 37°24'N Long. 14°55'E Elev. 24m

Summer 1978

Time GMT	Cloud Cover	Visibility (Kilometers)	Weather and Obstructions To Vision	Temp. (°C)	Dewpoint (°C)	Wind Direction (00-36)	Wind Speed (mps)	Remarks
Flight No. C-460 Date: 2 August 1978								
1400	Cloud Data Unknown	5.0	F-	34.2	14.2	07	6.1	Ceiling Unlimited
1500	Cloud Data Unknown	5.0	F-	34.2	14.2	07	6.1	Ceiling Unlimited
1600	Cloud Data Unknown	4.0	F-	33.2	15.2	07	6.1	Ceiling Unlimited
Other Area Meteorological Stations Reported 0/8 Clouds During this Afternoon								
Flight No. C-461 Date: 3 August 1978								
1300	Cloud Data Unknown	8.0	F-	37.2	18.2	09	6.1	Ceiling Unlimited
1400	Cloud Data Unknown	6.0	F-	36.2	18.2	09	6.1	Ceiling Unlimited
Flight No. C-462 Date: 5 August 1978								
1300	Cloud Data Unknown	MSG		34.2	19.2	08	7.7	Ceiling Not Specified
1400	Cloud Data Unknown	MSG		34.2	19.2	08	7.2	Ceiling Not Specified
Other Area Meteorological Stations Reported 0/8 Clouds During this Afternoon								
Flight No. C-463 Date: 7 August 1978								
1300	Cloud Data Unknown	MSG		37.2	18.2	09	6.6	Ceiling Not Specified
1400	Cloud Data Unknown	MSG		36.2	20.2	08	6.1	Ceiling Not Specified
1500	Cloud Data Unknown	MSG		35.2	22.2	08	5.1	Ceiling Not Specified

Winter 1978

Flight No. C-432 Date: 3 February 1978								
1500	Cloud data Unknown	11.2		13.2	3.2	30	3.6	Ceiling 3500 Feet
Flight No. C-433 Date: 17 February 1978								
1300	Cloud Data Unknown	11.2		19.2	10.2	27	5.1	Ceiling Unlimited
Flight No. C-434 Date: 18 February 1978								
1400	Cloud Data Unknown	11.2		19.2	6.2	32	3.0	Ceiling Unlimited

Table 3.2b Memmingen, Germany Standard Meteorological Data Sheet Lat. 47°59'N Long. 10°13'E Elev. 634m

Summer 1978

Time GMT	Cloud Cover	Visibility (Kilometers)	Weather and Obstructions To Vision	Temp. (°C)	Dewpoint (°C)	Wind Direction (00-36)	Wind Speed (mps)	Remarks
Flight No. C-471 Date: 11 September 1978								
1052	Cloud Data Unknown	11.2		20.2	10.2	24	9.7	Ceiling Unlimited
Flight No. C-473 Date: 11 September 1978								
1052	Cloud Data Unknown	11.2		20.2	10.2	24	9.7	Ceiling Unlimited

Winter 1978

Flight No. C-435 Date: 23 February 1978								
1052	Cloud Data Unknown	11.2		6.2	0.2	18	3.6	Ceiling 9000 Feet
Flight No. C-436 Date: 23 February 1978								
1552	Cloud Data Unknown	11.2		6.2	-1.8	06	2.5	Ceiling 13 000 Feet
Flight No. C-437 Date: 27 February 1978								
1352	Cloud Data Unknown	11.2		9.2	0.2	04	3.6	Ceiling 25 000 Feet
Flight No. C-439 Date: 1 March 1978								
1452	Cloud Data Unknown	5.0	H	5.2	0.2	03	1.5	Ceiling 9000 Feet

Table 3.2c Wunstorf, Germany Standard Meteorological Data Sheet Lat. 52°28′N Long. 09°25′E Elev. 57m

Summer 1978

Time GMT	Cloud Cover	Visibility (Kilometers)	Weather and Obstructions To Vision	Temp. (°C)	Dewpoint (°C)	Wind Direction (00-36)	Wind Speed (mps)	Remarks
Flight No. C-465 Date: 14 August 1978								
1544	Cloud Data Unknown	11.2		20.2	10.2	24	5.1	Ceiling 5000 Feet
Flight No. C-466 Date: 15 August 1978								
1244	4/8 Low or Middle Cloud	11.2		26.2	11.2	18	8.2	Ceiling Unlimited
1344	2/8 Low or Middle Cloud	11.2		27.2	11.2	17	7.2	Ceiling Unlimited
Flight No. C-468 Date: 21 August 1978								
1244	Cloud Data Unknown	11.2		27.2	12.2	27	1.5	Ceiling Unlimited
1344	Cloud Data Unknown	11.2		28.2	13.2	27	1.5	Ceiling Unlimited
Flight No. C-469 Date: 22 August 1978								
1544	Cloud Data Unknown	11.2		27.2	12.2	25	3.0	Ceiling Unlimited
1644	Cloud Data Unknown	11.2		24.2	11.2	25	2.5	Ceiling Unlimited

Winter 1978

Flight No. C-451 Date: 22 March 1978								
1444	Cloud Data Unknown	11.2		7.2	-1.8	24	4.6	Ceiling Unlimited RW-Last Hour
Flight No. C-452 Date: 23 March 1978								
1544	Cloud Data Unknown	11.2		13.3	2.2	25	7.2	Ceiling 3000 Feet RW-Last Hour
Flight No. C-454 Date: 28 March 1978								
1344	Cloud Data Unknown	11.2		14.2	7.2	20	4.1	Ceiling 5000 Feet
1444	Cloud Data Unknown	11.2		14.2	9.2	19	3.0	Ceiling 4500 Feet
Flight No. C-456 Date: 31 March 1978								
1644	Cloud Data Unknown	2.5		10.2	8.2	10	2.5	Ceiling 4000 Feet Drizzle Past Hour

Table 3.2d Mildenhall, England Standard Meteorological Data Sheet Lat. 52°22′N Long. 00°29′E Elev. 10m

Summer 1978

Time GMT	Cloud Cover	Visibility (Kilometers)	Weather and Obstructions To Vision	Temp. (°C)	Dewpoint (°C)	Wind Direction (00-36)	Wind Speed (mps)	Remarks
Flight No. C-475 Date: 15 September 1978								
1700	6/8 Low Clouds	11.2		17.2	13.2	28	4.1	Ceiling 3300 Feet
1800	7/8 Low Clouds	8.0	H	17.2	13.2	29	4.6	Ceiling 3500 Feet
Flight No. C-476 Date: 16 September 1978								
1500	Cloud Data Unknown	11.2		23.2	13.2	22	8.2+11.8	Gusts to 11.8 MPS Ceiling Unlimited
1600	Cloud Data Unknown	11.2		23.2	13.2	22	8.2+11.3	Gusts to 11.3 MPS Ceiling Unlimited
Flight No. C-477 Date: 18 September 1978								
1400	Cloud Data Unknown	11.2		18.2	7.2	28	6.1	Ceiling Unlimited
1500	Cloud Data Unknown	11.2		17.2	8.2	27	5.6	Ceiling 10 000 Feet

Winter 1978

Flight No. C-443 Date: 9 March 1978								
1600	Cloud Data Unknown	11.2		12.2	7.2	23	6.1	Ceiling 4000 Feet
Flight No. C-444 Date: 11 March 1978								
1600	Cloud Data Unknown	11.2		17.2	8.2	20	4.1+	Gusts 6.6 Ceiling Unlimited
Flight No. C-445 Date: 13 March 1978								
1300	Cloud Data Unknown	11.2		10.2	3.2	24	8.7	Ceiling 4000 Feet
Flight No. C-447 Date: 15 March 1978								
1500	Cloud Data Unknown	11.2		11.2	2.2	26	12.3+	Gusts to 18.0 Ceiling 20 000 Feet
Flight No. C-448 Date: 17 March 1978								
1500	Cloud Data Unknown	11.2		5.2	-1.8	36	5.1	Ceiling 3500 Feet

4. DATA PRESENTATION

4.1 Data and Flight Summary

During the summer of 1978 (2 Aug through 26 Sep), twenty flights were made in northern Europe, of which nineteen contained useable profile data. These data were reported in Johnson and Gordon, 1980. Of these nineteen, thirteen contained recoverable approach profiles. These thirteen flights are listed in Table 1.1.

During the preceding winter of 1978 (31 Jan through 31 Mar) twenty-seven flights were made in the same European regions of which twenty-six contained useable profile data. These data were reported in Johnson and Gordon, 1979. Of these twenty-six, sixteen contained recoverable approach profiles, which are also listed with their appropriate descriptors in Table 1.1.

4.2 Description of Data Tables and Graphs

The flight data for the APPROACH sequences listed in Table 1.1 are presented in both tabular and graphical format. The winter and summer measurements at each of four aerodromes appear as paired displays for ease of comparison.

The scattering coefficient profiles represent measurements made continuously during each final descent which have been averaged vertically to yield one data point every 30 meters in altitude. The measurements were all made using a pseudo-photopic spectral response having a mean wavelength of 557 nm. Altitudes are reported in meters above ground level (AGL).

4.3 Supplementary Data Entries

In the tabular displays, four additional entries have been included as peripheral information. The first is the local visibility reported by the station meteorologist and abstracted from Table 3.2. The second is the ground level scattering coefficient (s), as measured by the C-130 nephelometer, converted to approximate visual range (VR) via the expression

$$VR \approx 3/s$$

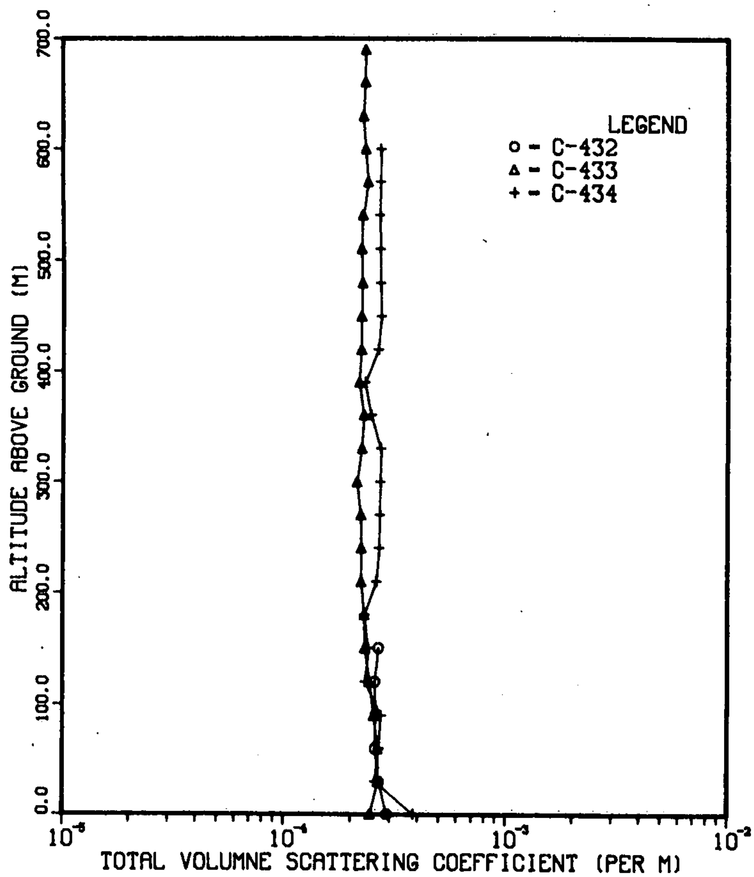
as discussed by Douglas and Young (1945), Middleton (1952) and Gordon (1979). A comparison was anticipated between these measured values and the visual estimates made by the aerodrome meteorological observer, however for all but five of the twenty-nine landing intervals, the meteorological report was truncated at 11.2 km (7 statute miles) *i.e.* VV>11.2 km was reported as 11.2 km. This common aeronautical practice precluded the accumulation of an adequate comparative data base and thus no further comparison attempts were made. The reported visual estimates are however, included in the supplementary data for the reader's convenience.

The third peripheral item is the measurement of total downwelling illumination at the time of landing. These measurements, also made in the pseudo-photopic spectral band, are reported in units of *lux* ($lumens/m^2$) and can be compared directly with standard tables of natural illumination such as Brown (1952) by utilizing the location and time information listed in Table 4.1. These specific comparisons however, have not been included in this report.

The final supplementary entry is the time of landing touchdown. These times, indicated in GMT, have been extracted from Table 4.1 and truncated to hours and minutes only.

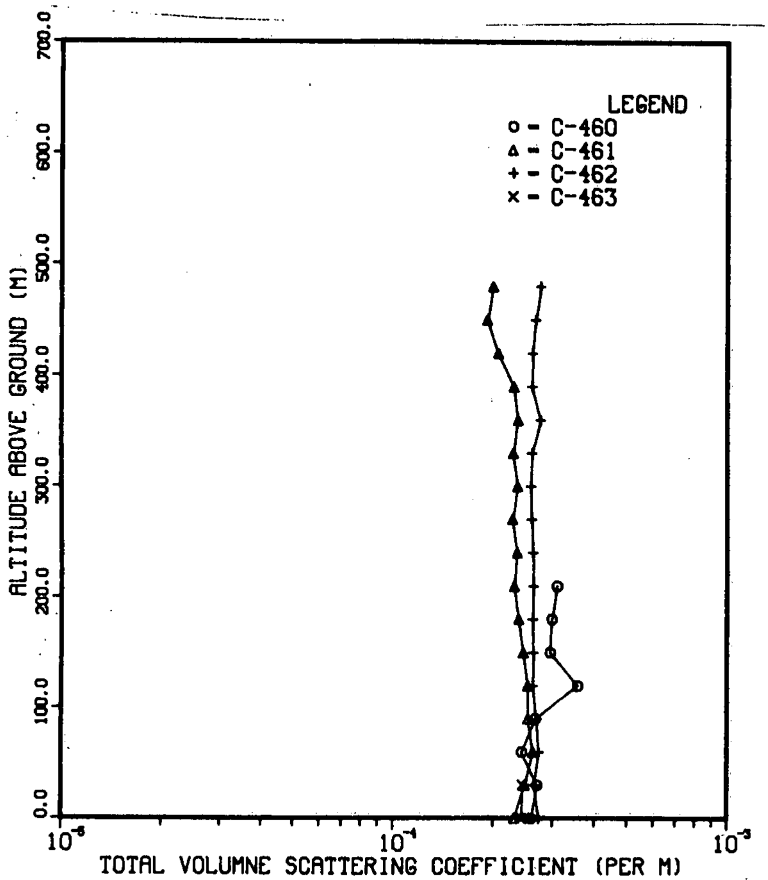
Fig. 4-1.

APPROACH PROFILES - GRAPHICAL



Sigonella, Sicily

Winter, 1978



Sigonella, Sicily

Summer, 1978

Table 4.1.

APPROACH PROFILES - TABULAR

Sigonella, Sicily

Winter 1978

Altitude (m) AGL	Total Volume Scattering Coefficient (m^{-1})				
	C432	C433	C434		
690.		2.327E-04			
660.		2.320E-04			
630.		2.272E-04			
600.		2.325E-04	2.712E-04		
570.		2.378E-04	2.693E-04		
540.		2.244E-04	2.670E-04		
510.		2.212E-04	2.676E-04		
480.		2.233E-04	2.687E-04		
450.		2.214E-04	2.707E-04		
420.		2.213E-04	2.631E-04		
390.		2.172E-04	2.297E-04		
360.		2.278E-04	2.456E-04		
330.		2.231E-04	2.712E-04		
300.		2.126E-04	2.703E-04		
270.		2.216E-04	2.682E-04		
240.		2.226E-04	2.675E-04		
210.		2.227E-04	2.602E-04		
180.		2.300E-04	2.300E-04		
150.	2.670E-04	2.318E-04	2.402E-04		
120.	2.572E-04	2.437E-04	2.332E-04		
90.	2.596E-04	2.550E-04	2.735E-04		
60.	2.579E-04	2.651E-04	2.674E-04		
30.	2.687E-04	2.658E-04	2.580E-04		
0.	2.917E-04	2.451E-04	3.825E-04		
Visibility (km)	⩾11.2	⩾11.2	⩾11.2		
Visual Range (km)	10	12	8		
Illumination (lux)	2900	24400	18900		
Landing Time (GMT)	1500	1308	1400		

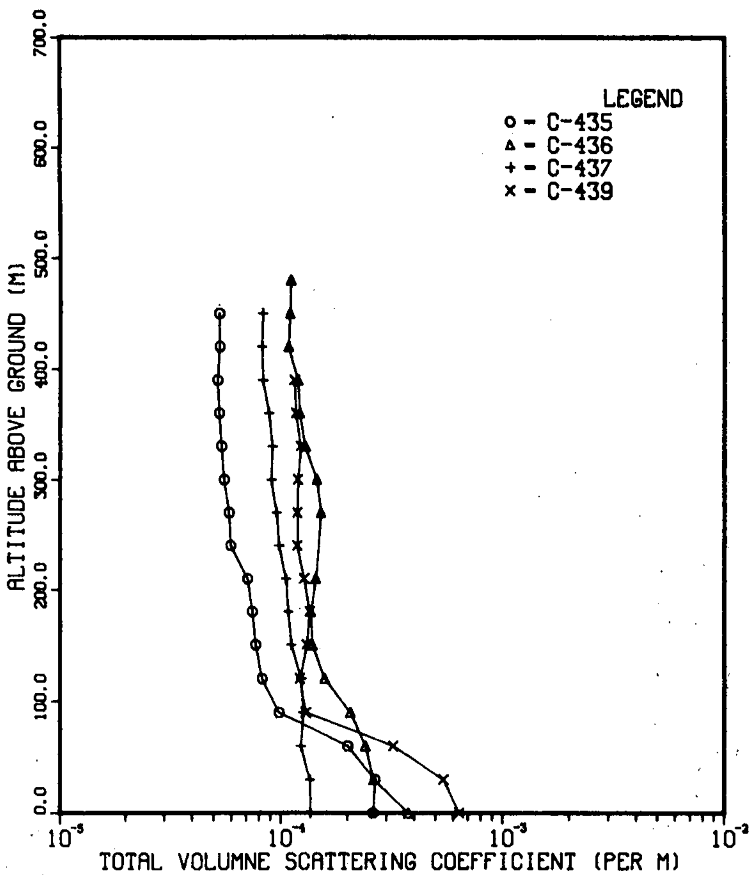
Sigonella, Sicily

Summer 1978

Altitude (m) AGL	Total Volume Scattering Coefficient (m^{-1})				
	C460	C461	C462	C463	
480.		1.993E-04	2.762E-04		
450.		1.911E-04	2.663E-04		
420.		2.065E-04	2.603E-04		
390.		2.301E-04	2.602E-04		
360.		2.367E-04	2.759E-04		
330.		2.290E-04	2.600E-04		
300.		2.362E-04	2.582E-04		
270.		2.284E-04	2.602E-04		
240.		2.360E-04	2.623E-04		
210.	3.101E-04	2.311E-04	2.637E-04		
180.	2.990E-04	2.383E-04	2.618E-04		
150.	2.958E-04	2.466E-04	2.634E-04		
120.	3.568E-04	2.539E-04	2.626E-04		
90.	2.673E-04	2.543E-04	2.691E-04		
60.	2.437E-04	2.632E-04	2.734E-04		
30.	2.706E-04	2.484E-04	2.653E-04	2.452E-04	
0.	2.600E-04	2.312E-04	2.733E-04	2.429E-04	
Visibility (km)	4-5	8	MSG	MSG	
Visual Range (km)	12	13	11	12	
Illumination (lux)	30600	89900	86300	84600	
Landing Time (GMT)	1549	1247	1322	1341	

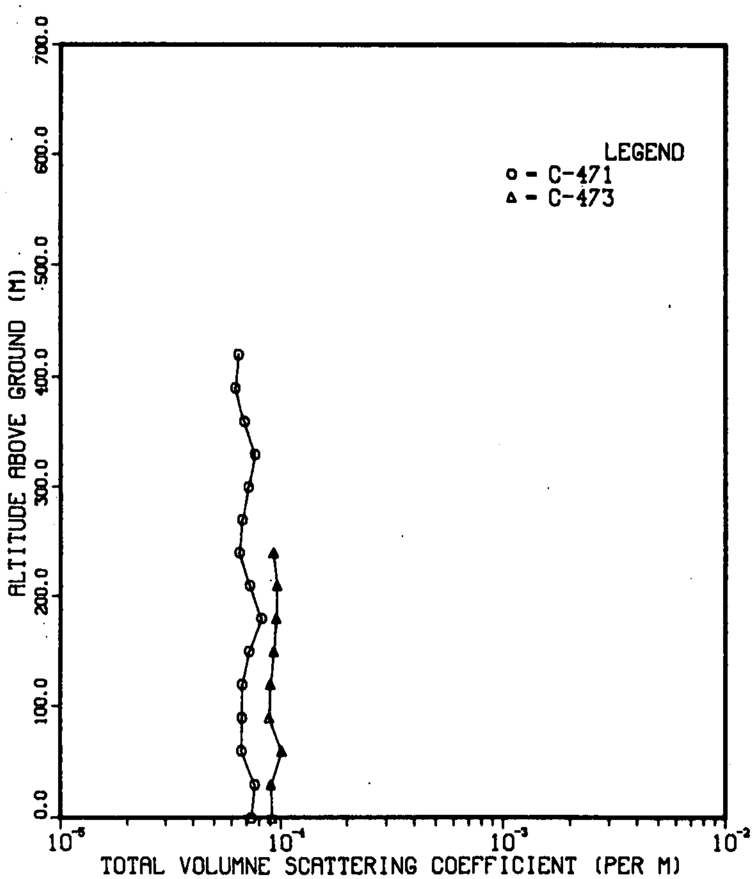
Fig. 4-2.

APPROACH PROFILES - GRAPHICAL



Memmingen, Germany

Winter, 1978



Memmingen, Germany

Summer, 1978

Table 4.2.

APPROACH PROFILES - TABULAR

Memmingen, Germany

Winter 1978

Altitude (m) AGL	Total Volume Scattering Coefficient (m^{-1})				
	C435	C436	C437	C439	
480.		1.110E-04			
450.	5.273E-05	1.100E-04	8.281E-05		
420.	5.295E-05	1.083E-04	8.227E-05		
390.	5.188E-05	1.197E-04	8.321E-05	1.147E-04	
360.	5.279E-05	1.215E-04	8.863E-05	1.169E-04	
330.	5.408E-05	1.287E-04	9.167E-05	1.227E-04	
300.	5.566E-05	1.454E-04	9.077E-05	1.192E-04	
270.	5.863E-05	1.516E-04	9.578E-05	1.184E-04	
240.	5.949E-05	1.476E-04	9.842E-05	1.186E-04	
210.	7.090E-05	1.436E-04	1.056E-04	1.275E-04	
180.	7.465E-05	1.364E-04	1.081E-04	1.350E-04	
150.	7.721E-05	1.390E-04	1.116E-04	1.308E-04	
120.	8.243E-05	1.582E-04	1.239E-04	1.218E-04	
90.	9.837E-05	2.064E-04	1.261E-04	1.295E-04	
60.	2.006E-04	2.411E-04	1.232E-04	3.231E-04	
30.	2.671E-04	2.633E-04	1.351E-04	5.433E-04	
0.	2.605E-04	3.775E-04	1.356E-04	6.409E-04	
Visibility (km)	⩾11.2	⩾11.2	⩾11.2	5	
Visual Range (km)	11	8	22	5	
Illumination (lux)	55100	14000	26900	2100	
Landing Time (GMT)	1043	1524	1358	1456	

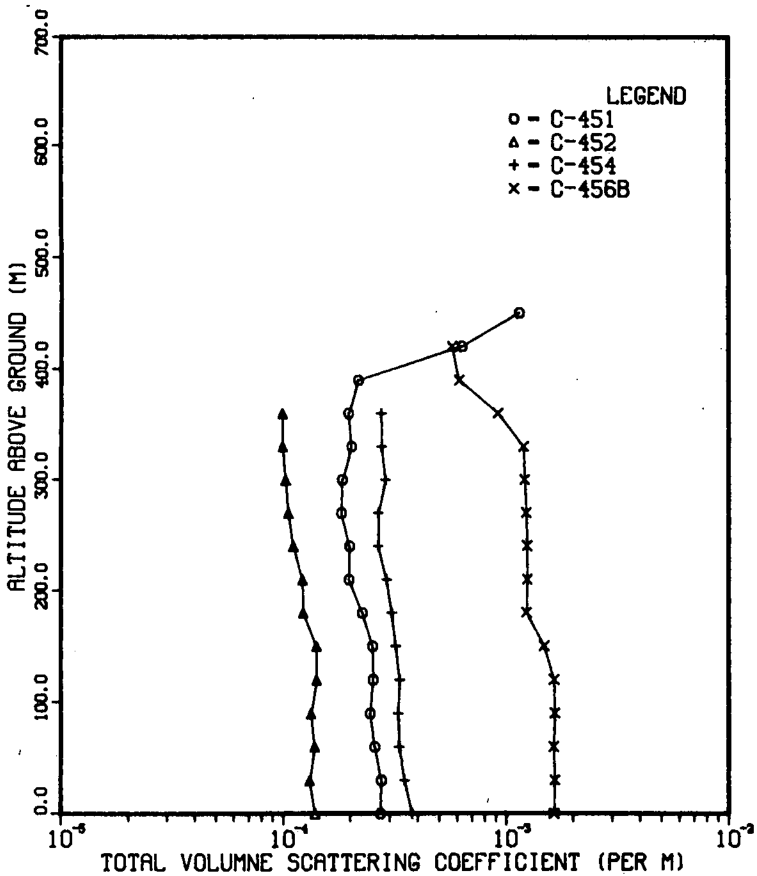
Memmingen, Germany

Summer 1978

Altitude (m) AGL	Total Volume Scattering Coefficient (m^{-1})				
	C471	C473			
420.	6.398E-05				
390.	6.183E-05				
360.	6.804E-05				
330.	7.601E-05				
300.	7.105E-05				
270.	6.671E-05				
240.	6.480E-05	9.282E-05			
210.	7.215E-05	9.645E-05			
180.	8.172E-05	9.540E-05			
150.	7.175E-05	9.302E-05			
120.	6.677E-05	8.990E-05			
90.	6.662E-05	8.872E-05			
60.	6.623E-05	1.012E-04			
30.	7.618E-05	9.052E-05			
0.	7.330E-05	9.137E-05			
Visibility (km)	⩾11.2	⩾11.2			
Visual Range (km)	41	33			
Illumination (lux)	90100	14600			
Landing Time (GMT)	0929	1636			

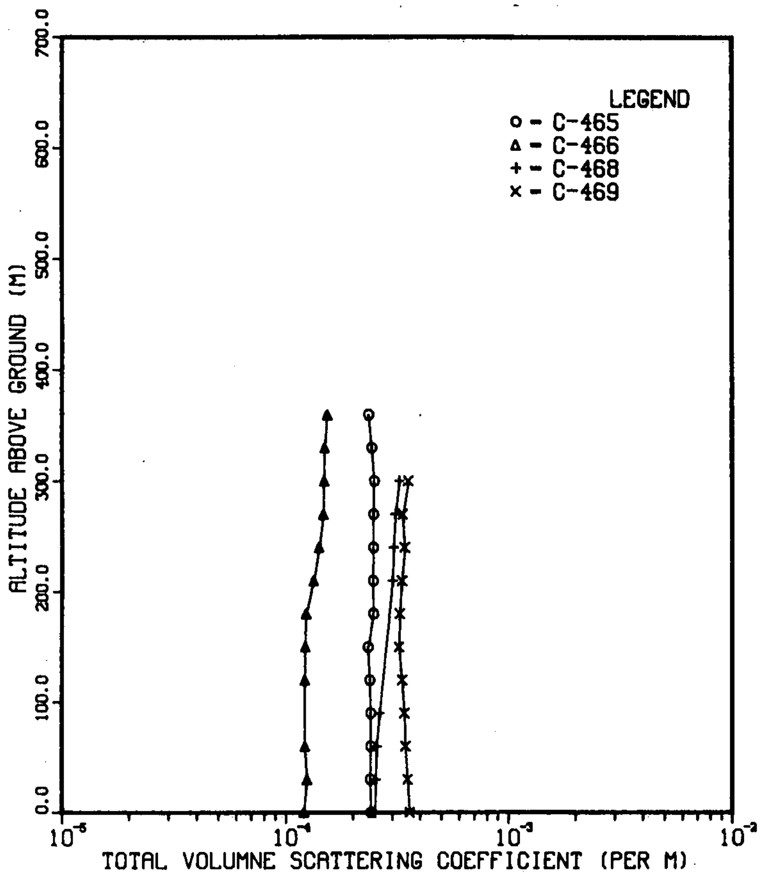
Fig. 4-3.

APPROACH PROFILES - GRAPHICAL



Wunstorf, Germany

Winter, 1978



Wunstorf, Germany

Summer, 1978

Table 4.3.

APPROACH PROFILES - TABULAR

Wunstorf, Germany

Winter 1978

Altitude (m) AGL	Total Volume Scattering Coefficient (m^{-1})				
	C451	C452	C454	C456B	
450.	1.138E-03				
420.	6.286E-04			5.673E-04	
390.	2.154E-04			6.096E-04	
360.	1.948E-04	9.892E-05	2.740E-04	9.132E-04	
330.	2.013E-04	9.904E-05	2.743E-04	1.192E-03	
300.	1.831E-04	1.0204	3.058E-04	1.230E-03	
150.	2.515E-04	1.408E-04	3.180E-04	1.479E-03	
120.	2.527E-04	1.407E-04	3.316E-04	1.639E-03	
90.	2.451E-04	1.328E-04	3.260E-04	1.656E-03	
60.	2.572E-04	1.380E-04	3.300E-04	1.634E-03	
30.	2.758E-04	1.309E-04	3.485E-04	1.653E-03	
0.	2.720E-04	1.389E-04	3.783E-04	1.642E-03	
Visibility (km)	⩾11.2	⩾11.2	⩾11.2	2.5	
Visual Range (km)	11	21	8	2	
Illumination (lux)	43600	8800	43200	1900	
Landing Time (GMT)	1445	1608	1414	1637	

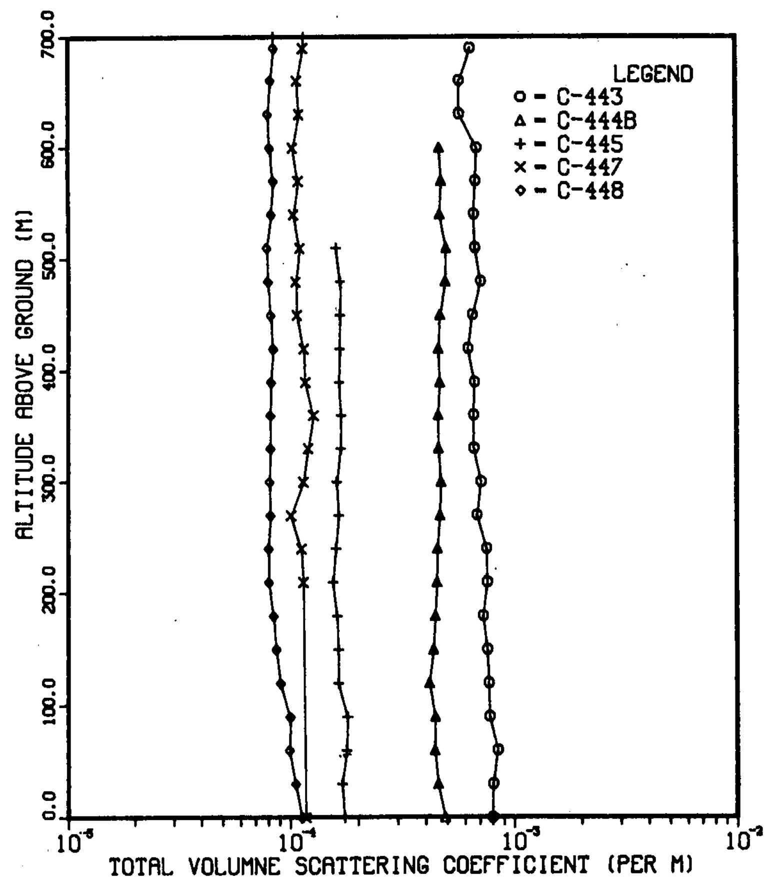
Wunstorf, Germany

Summer 1978

Altitude (m) AGL	Total Volume Scattering Coefficient (m^{-1})				
	C465	C466	C468	C469	
360.	2.364E-04	1.542E-04			
330.	2.443E-04	1.502E-04			
300.	2.503E-04	1.494E-04	3.248E-04	3.555E-04	
270.	2.483E-04	1.479E-04	3.104E-04	3.362E-04	
240.	2.484E-04	1.417E-04	3.053E-04	3.426E-04	
210.	2.478E-04	1.339E-04	3.022E-04	3.333E-04	
180.	2.482E-04	1.236E-04	2.924E-04	3.257E-04	
150.	2.346E-04	1.228E-04	2.826E-04	3.224E-04	
120.	2.383E-04	1.221E-04	2.728E-04	3.334E-04	
90.	2.404E-04	1.220E-04	2.630E-04	3.404E-04	
60.	2.409E-04	1.218E-04	2.556E-04	3.446E-04	
30.	2.391E-04	1.245E-04	2.527E-04	3.516E-04	
0.	2.416E-04	1.206E-04	2.512E-04	3.601E-04	
Visibility (km)	⩾11.2	⩾11.2	⩾11.2	⩾11.2	
Visual Range (km)	12	25	12	8	
Illumination (lux)	23500	86300	73200	29400	
Landing Time (GMT)	1536	1341	1314	1609	

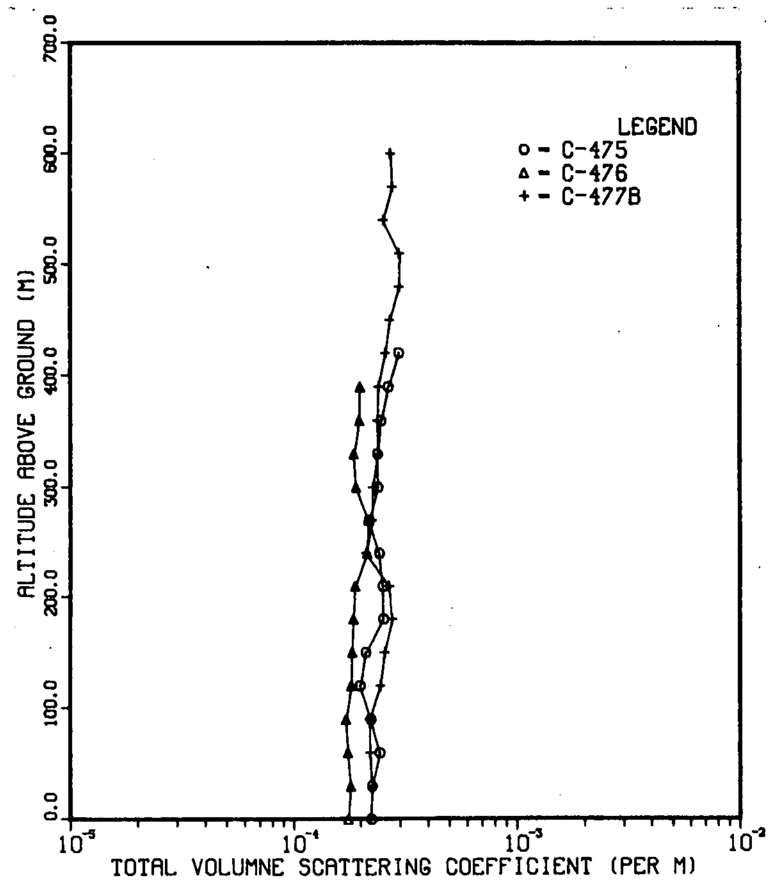
Fig. 4-4.

APPROACH PROFILES - GRAPHICAL



Mildenhall, England

Winter, 1978



Mildenhall, England

Summer, 1978

Table 4.4.

APPROACH PROFILES - TABULAR

Mildenhall, England

Winter 1978

Altitude (m) AGL	Total Volume Scattering Coefficient (m^{-1})				
	C443	C444B	C445	C447	C448
810.				1.116E-04	
780.				1.232E-04	
750.				1.243E-04	
720.				1.164E-04	8.401E-05
690.	6.405E-04			1.148E-04	8.485E-05
660.	5.718E-04			1.077E-04	8.201E-05
630.	5.728E-04			1.101E-04	7.988E-05
600.	6.838E-04	4.661E-04		1.033E-04	8.163E-05
570.	6.734E-04	4.765E-04		1.089E-04	8.450E-05
540.	6.635E-04	4.678E-04		1.038E-04	8.237E-05
510.	6.709E-04	4.995E-04	1.605E-04	1.107E-04	7.880E-05
480.	7.103E-04	4.952E-04	1.673E-04	1.062E-04	8.000E-05
450.	6.521E-04	4.683E-04	1.670E-04	1.075E-04	8.206E-05
420.	6.227E-04	4.598E-04	1.665E-04	1.153E-04	8.409E-05
390.	6.657E-04	4.668E-04	1.654E-04	1.171E-04	8.228E-05
360.	6.597E-04	4.587E-04	1.687E-04	1.274E-04	8.181E-05
330.	6.615E-04	4.592E-04	1.683E-04	1.206E-04	8.176E-05
300.	7.122E-04	4.721E-04	1.617E-04	1.147E-04	8.107E-05
270.	6.817E-04	4.660E-04	1.648E-04	1.012E-04	8.169E-05
240.	7.524E-04	4.539E-04	1.602E-04	1.124E-04	8.019E-05
210.	7.595E-04	4.525E-04	1.554E-04	1.149E-04	8.053E-05
180.	7.260E-04	4.440E-04	1.623E-04	1.152E-04	8.434E-05
150.	7.584E-04	4.357E-04	1.642E-04	1.155E-04	8.680E-05
120.	7.685E-04	4.165E-04	1.642E-04	1.158E-04	9.077E-05
90.	7.755E-04	4.424E-04	1.798E-04	1.161E-04	1.000E-04
60.	8.448E-04	4.406E-04	1.777E-04	1.164E-04	9.925E-05
30.	8.040E-04	4.554E-04	1.697E-04	1.167E-04	1.057E-04
0.	7.992E-04	4.898E-04	1.745E-04	1.170E-04	1.128E-04
Visibility (km)	⩾11.2	⩾11.2	⩾11.2	5	MSG
Visual Range (km)	4	6	17		27
Illumination (lux)	16500	10800	35600	21900	20400
Landing Time (GMT)	1557	1624	1326	1504	1449

Mildenhall, England

Summer 1978

Altitude (m) AGL	Total Volume Scattering Coefficient (m^{-1})				
	C475	C476	C477B		
600.			2.733E-04		
570.			2.779E-04		
540.			2.530E-04		
510.			2.991E-04		
480.			2.981E-04		
450.			2.703E-04		
420.	2.965E-04		2.576E-04		
390.	2.661E-04	1.997E-04	2.391E-04		
360.	2.471E-04	1.977E-04	2.371E-04		
330.	2.376E-04	1.870E-04	2.379E-04		
300.	2.395E-04	1.912E-04	2.255E-04		
270.	2.177E-04	2.174E-04	2.243E-04		
240.	2.419E-04	2.136E-04	2.109E-04		
210.	2.509E-04	1.894E-04	2.678E-04		
180.	2.530E-04	1.860E-04	2.760E-04		
150.	2.109E-04	1.834E-04	2.544E-04		
120.	1.981E-04	1.812E-04	2.437E-04		
90.	2.212E-04	1.717E-04	2.178E-04		
60.	2.429E-04	1.754E-04	2.189E-04		
30.	2.240E-04	1.803E-04	2.251E-04		
0.	2.226E-04	1.760E-04	2.201E-04		
Visibility (km)	8-11	⩾11.2	⩾11.2		
Visual Range (km)	13	17	14		
Illumination (lux)	-	42400	30300		
Landing Time (GMT)	1746	1538	1525		

5. DATA DISCUSSION

As noted in the introductory remarks of section 1, the accurate specification of the atmospheric volume scattering characteristics at very low altitudes can be critical to the determination of slant path contrast transmittances through this near surface regime. It is of major importance for one to know, or be able to reliably deduce, the occurrence of major variations in the vertical structure of the atmospheric aerosol. The flight data represented in the earlier referenced reports, Johnson and Gordon, 1980 etc., have provided extensive samples of these variations and thus have served as the case studies required for developing reasonable modelling representations. A preliminary discussion of a proposed modelling technique was originally discussed in Johnson *et al.* 1979, has been amplified upon in Johnson and Hering, 1981, and is described further in Hering, 1981.

Since the profile data upon which the Hering model was developed terminated at 500 to 1000 ft. (150-300m) above the ground, the confidence with which one could specify the low level scattering properties from these data was somewhat compromised. The data presented in section 4 of this current report specifically address the resolution of the uncertainty in this specification. They support the contention that in most cases, midday measurements of atmospheric volume scattering coefficient made within the 150-300m AGL altitude regime may be reliably extrapolated down to the surface with only marginal risk of significant error within the context of overall model performance. Of the twenty-nine winter and summer profiles illustrated in section 4, only three, the winter measurements in Memmingen, show marked increases in low level haze. There is additionally one minor increase at the surface illustrated by flight 434 (winter/Sigonella), but it is not nearly as deep nor extensive a shift as is indicated in the Memmingen measurements. The specific conditions contributing to these four very low altitude phenomena have not yet been identified.

One other characteristic of this admittedly limited data sample that is of interest, and may bear additional modelling implications is the relative spread in the seasonal scattering coefficient magnitudes. With the singular exception of the Sigonella data, the winter measurements represent a considerably broader variation in scattering coefficient values than do the summer measurements. This is particularly apparent in the Mildenhall data, and is a feature that can be commented upon with greater confidence as the low altitude data sample increases. As noted by the landing times for each flight, these data represent midday measurements for the most part, and thus are biased in favor of well mixed, vertically stable conditions. They will not reflect the near surface conditions associated with early morning or evening heavy hazes and fogs.

5.1 Summary

Twenty-nine vertical profiles of the photopic atmospheric volume scattering coefficient representing both winter and summer conditions at four separate European aerodromes have been presented for evaluation. The basic question to be addressed is whether or not the scattering coefficient profile remains reasonably constant as one approaches the surface from an altitude of several hundred meters, and if not, what is the character of the vertical structure. These data indicate that in twenty-six out of twenty-nine instances, the profile is essentially constant in value and thus the modelling approach proposed by Hering (1981) is in fact an appropriate procedure. The identification of the conditions resulting in the three profiles showing abrupt near-surface increases in haziness should be addressed as a separate problem, when the larger four season data base has been developed.

6. ACKNOWLEDGEMENTS

This report has been prepared for the Air Force Geophysics Laboratory under Contract No. F19628-78-C-0200. The author wishes to thank the members of the Visibility Laboratory technical staff for their assistance in preparing these data, and in particular to acknowledge the contributions of Mr. Nils R. Persson, our senior computer specialist, and Ms. Alicia G. Hill and Mr. John C. Brown our specialists in computer assisted document preparation.

7. REFERENCES

Brown, D. R. E. (1952), *Natural Illumination Charts,* Report 374-1, Project Ns-714-100, Department of the Navy, Bureau of Ships, Washington, D.C.

Douglas, C. A. and L. L. Young (1945), "Development of Transmissometer for Determining Visual Range", U.S. Department of Commerce, Civil Aeronautics Administration, Washington, D.C., Technical Development Report No. 47.

Fenn, R. W. (1978), "OPAQUE - A Measurement Program on Optical Atmospheric Quantities in Europe, Vol. I The NATO OPAQUE Program", Special Reports No. 211, AFGL-TR-78-0011.

Gordon, J. I. (1979), "Daytime Visibility, a Conceptual Review", University of California at San Diego, Scripps Institution of Oceanography, Visibility Laboratory, SIO Ref. 80-1, AFGL-TR-79-0257.

Hering, W. S. (1981), "An Assessment of Operational Techniques for Estimating Visible Spectrum Contrast Transmittance", Paper presented at the 25th Annual Technical Symposium of the Society of Photo-Optical Instrumentation Engineers, Seminar on Atmospheric Effects on Electro-Optical, Infrared and Millimeter Wave System Performance, San Diego, California. (Aug. 1981)

Johnson, R. W. and W. S. Hering (1981), "Measurements of Optical Atmospheric Quantities in Europe and Their Application to Modelling

Visible Spectrum Contrast Transmittance", Paper presented at the 29th Symposium of the AGARD Electromagnetic Wave Propagation Panel on Special Topics in Optical Propagation, Monterey, California. (April, 1981)

Johnson, R. W., W. S. Hering, J. I. Gordon, B. W. Fitch and J. E. Shields (1979), "Preliminary Analysis and Modelling Based Upon Project OPAQUE Profile and Surface Data", University of California, San Diego, Scripps Institution of Oceanography, Visibility Laboratory, SIO Ref. 80-5, AFGL-TR-79-0285.

Johnson, R. W. and J. I. Gordon (1979), "Airborne Measurements of Atmospheric Volume Scattering Coefficients in Northern Europe, Winter 1978", University of California, San Diego, Scripps Institution of Oceanography, Visibility Laboratory, SIO Ref. 79-25, AFGL-TR-79-0159.

Johnson, R. W. and J. I. Gordon (1980), "Airborne Measurements of Atmospheric Volume Scattering Coefficients in Northern Europe, Summer 1978", University of California, San Diego, Scripps Institution of Oceanography, Visibility Laboratory, SIO Ref. 80-20, AFGL-TR-80-0207.

Middleton, W. E. K. (1952), *Vision Through the Atmosphere*, Chapter 10, University of Toronto Press.

APPENDIX A

METEOROLOGICAL GLOSSARY & ABBREVIATIONS

SKY AND CEILING

Sky cover symbols are in ascending order. Figures preceding symbols are heights in hundreds of feet above station. Sky cover symbols are:

- ○ Clear: less than 0.1 sky cover
- ⦶ Scattered: 0.1 to less than 0.6 sky cover
- ⦷ Broken: 0.6 to 0.9 sky cover
- ⊕ Overcast: more than 0.9 sky cover
- \- Thin (when prefixed); light (when suffixed)
- \-- Very light (when suffixed)
- -X Partial obscuration: 0.1 to less than 1.0 sky hidden by precipitation or obstruction to vision (bases at surface)
- X Obscuration: 1.0 sky hidden by precipitation or obstruction to vision (bases at surface)

Letter preceding height of layer identifies ceiling layer and indicates how ceiling height was obtained. Thus:

- A Aircraft
- B Balloon (pilot or ceiling)
- D Estimated height of cirriform clouds on basis of persistency
- E Estimated height of noncirriform clouds
- M Measured
- R Radiosonde balloon or radar
- U Height of cirriform ceiling layer unknown
- V Immediately following numerical value indicates a varying ceiling (also used with varying visibility)
- W Indefinite, sky obscured by surface base phenomenon. e.g. fog, blowing dust, snow

RELATIVE HUMIDITY (RH)

Reported in percent and computed from temperature and dewpoint.

VISIBILITY (VV)

Reported in kilometers.

WEATHER AND OBSTRUCTION TO VISION SYMBOLS

A	Hail	IF	Ice fog
AP	Small hail	K	Smoke
BD	Blowing dust	L	Drizzle
BN	Blowing sand	R	Rain
BS	Blowing snow	RW	Rain showers
D	Dust	S	Snow
E	Sleet	SG	Snow grains
EW	Sleet showers	SP	Snow pellets
F	Fog	SW	Snow showers
GF	Ground fog	T	Thunderstorms
H	Haze	ZL	Freezing drizzle
IC	Ice crystals	ZR	Freezing rain

CLOUD ABBREVIATIONS

Ac	Altocumulus	Cs	Cirrostratus
As	Altostratus	Cu	Cumulus
Cb	Cumulonimbus	Ns	Nimbostratus
Cc	Cirrocumulus	Sc	Stratocumulus
Ci	Cirrus	St	Stratus

WIND

Direction in ten's of degrees from true north, speed in meters per second (mps). A "0000" indicates calm. A "G" indicates gusty. A "Q" indicates squall. Peak speed of gusts, when reported, follows G or Q. The contraction WSHFT in remarks followed by time group (GMT) indicates wind shift and its time of occurrence.

Examples: 0109 is 010 degrees, 9 mps.
3607G11 is 360 degrees, 7 mps, peak speed in gusts of 11 mps.

MSG: Data missing in original source.

APPENDIX B

VISIBILITY LABORATORY CONTRACTS AND RELATED PUBLICATIONS

Previous Related Contracts:
F19628-73-C-0013, F19628-76-C-0004

PUBLICATIONS:

Duntley, S. Q., R. W. Johnson, and J. I. Gordon (1972), "Airborne Measurements of Optical Atmospheric Properties in Southern Germany", University of California at San Diego, Scripps Institution of Oceanography, Visibility Laboratory, SIO Ref. 72-64, AFCRL-72-0255.

Duntley, S. Q., R. W. Johnson, and J. I. Gordon (1972), "Airborne and Ground-Based Measurements of Optical Atmospheric Properties in Central New Mexico", University of California at San Diego, Scripps Institution of Oceanography, Visibility Laboratory, SIO Ref. 72-71, AFCRL-72-0461.

Duntley, S. Q., R. W. Johnson, and J. I. Gordon (1972), "Airborne Measurements of Optical Atmospheric Properties, Summary and Review", University of California at San Diego, Scripps Institution of Oceanography, Visibility Laboratory, SIO Ref. 72-82, AFCRL-72-0593.

Duntley, S. Q., R. W. Johnson, and J. I. Gordon (1973), "Airborne Measurements of Optical Atmospheric Properties in Southern Illinois", University of California at San Diego, Scripps Institution of Oceanography, Visibility Laboratory, SIO Ref. 73-24, AFCRL-TR-73-0422.

Duntley, S. Q., R. W. Johnson, and J. I. Gordon (1974), "Airborne and Ground-Based Measurements of Optical Atmospheric Properties in Southern Illinois", University of California at San Diego, Scripps Institution of Oceanography, Visibility Laboratory, SIO Ref. 74-25, AFCRL-TR-74-0298.

Duntley, S. Q., R. W. Johnson, and J. I. Gordon (1975), "Airborne Measurements of Optical Atmospheric Properties in Western Washington", University of California at San Diego, Scripps Institution of Oceanography, Visibility Laboratory, SIO Ref. 75-24, AFCRL-TR-75-0414.

Duntley, S. Q., R. W. Johnson, and J. I. Gordon (1975), "Airborne Measurements of Optical Atmospheric Properties, Summary and Review II", University of California at San Diego, Scripps Institution of Oceanography, Visibility Laboratory, SIO Ref. 75-26, AFCRL-TR-75-0457.

Duntley, S. Q., R. W. Johnson, and J. I. Gordon (1976), "Airborne Measurements of Optical Atmospheric Properties in Northern Germany", University of California at San Diego, Scripps Institution of Oceanography, Visibility Laboratory, SIO Ref. 76-17, AFGL-TR-76-0188.

Duntley, S. Q., R. W. Johnson, and J. I. Gordon (1977), "Airborne Measurements of Atmospheric Volume Scattering Coefficients in Northern Europe, Spring 1976", University of California at San Diego, Scripps Institution of Oceanography, Visibility Laboratory, SIO Ref. 77-8, AFGL-TR-77-0078.

Duntley, S. Q., R. W. Johnson, and J. I. Gordon (1978), "Airborne Measurements of Atmospheric Volume Scattering Coefficients in Northern Europe, Fall 1976", University of California at San Diego, Scripps Institution of Oceanography, Visibility Laboratory, SIO Ref. 78-3, AFGL-TR-77-0239.

Duntley, S. Q., R. W. Johnson, and J. I. Gordon (1978), "Airborne Measurements of Atmospheric Volume Scattering Coefficients in Northern Europe, Summer 1977", University of California at San Diego, Scripps Institution of Oceanography, Visibility Laboratory, SIO Ref. 78-28, AFGL-TR-78-0168.

Duntley, S. Q., R. W. Johnson, and J. I. Gordon (1978), "Airborne Measurements of Optical Atmospheric Properties, Summary and Review III", University of California at San Diego, Scripps Institution of Oceanography, Visibility Laboratory, SIO Ref. 79-5, AFGL-TR-78-0286.

Gordon, J. I., J. L. Harris, Sr., and S. Q. Duntley (1973), "Measuring Earth-to-Space Contrast Transmittance from Ground Stations", Appl. Opt. 12, 1317-1324.

Gordon, J. I., C. F. Edgerton, and S. Q. Duntley (1975), "Signal-Light Nomogram", J. Opt. Soc. Am. 65, 111-118.

Gordon, J. I., (1979), "Daytime Visibility, A Conceptual Review", University of California at San Diego, Scripps Institution of Oceanography, Visibility Laboratory, SIO Ref. 80-1, AFGL-TR-79-0257.

Johnson, R. W., and J. I. Gordon (1979). "Airborne Measurements of Atmospheric Volume Scattering Coefficients in Northern Europe, Winter 1978", University of California at San Diego, Scripps Institution of Oceanography, Visibility Laboratory, SIO Ref. 79-25, AFGL-TR-79-0159.

Johnson, R. W., W. S. Hering, J. I. Gordon, B. W. Fitch, and J. S. Shields (1979), "Preliminary Analysis & Modelling Based Upon Project OPAQUE Profile and Surface Data", University of California at San Diego, Scripps Institution of Oceanography, Visibility Laboratory, SIO Ref. 80-5, AFGL-TR-79-0285.

Johnson, R. W. and J. I. Gordon (1980), "Airborne Measurements of Atmospheric Volume Scattering Coefficients in Northern Europe, Summer 1978", University of California at San Diego, Scripps Institution of Oceanography, Visibility Laboratory, SIO Ref. 80-20, AFGL-TR-80-0207.