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SPRING AND FALL MEASUREMENTS OF EUROPEAN VERY LOW ALTITUDE VOLUME SCATTERING COEFFICIENTS

Richard W. Johnson

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Contract Monitor, Major John D. Mill, USAF
Optical Physics Division

Prepared for
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20. ABSTRACT continued:

The data illustrate that in twenty-two of twenty-five 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.

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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 25 low altitude scattering coefficient profiles and related meteorological data that were measured mostly during the Spring and Fall seasons of 1976 and 1977 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). Similar data covering the Winter and Summer seasons of 1978 have been presented in an earlier report, AFGL-TR-81-0154, Johnson (1981a).

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 desirable.

The reported data illustrate that in twenty-two out of twenty-five 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.

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SPRING AND FALL 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).

As discussed briefly in the earlier issuance of this two report series, i.e. AFGL-TR-81-0154, Johnson (1981a), there has been a systematic gap in the data describing the vertical variations in low altitude atmospheric scattering coefficients, which has been particularly troublesome when addressing the performance of low flying electro-optical systems. The data contained in this

Spring-Fall report in conjunction with the previously presented Winter-Summer data set are intended to reduce substantially the uncertainties in the structure of the near surface scattering coefficient profile.

An identification of the flight data included in this Spring-Fall report is provided in Table 1.1. As in the Winter-Summer set, these data represent measurements made following each experimental data flight during the instrumented aircraft's approach and landing sequences. The flights indicated in Table 1.1 are mostly from the OPAQUE I, II and III deployments, Duntley *et al.* (1977, 1978a and 1978b). For completeness, two flights made at Vaerloose, Denmark during the summer of 1978 have been included with the summer of 1977 data.

Table 1.1.
Flight Identification Data

Aerodrome Identification	Flight No	Flight Date	Landing Time (GMT)
Wunstorf, Germany 52°28'N 09°25'E 57m MSL	381	25 May 76	14 28 03
	392	1 Nov 76	13 23 29
	393	2 Nov 76	11 50 35
	394	18 Nov 76	13 58 34
	396	22 Nov 76	11 05 50
	397	23 Nov 76	14 10 53
	414	28 Jul 77	11 59 28
	415	29 Jul 77	12 49 11
	416	1 Aug 77	15 36 51
	418	4 Aug 77	10 46 50
	419	4 Aug 77	16 47 35
Vaerloose, Denmark 55°46'N 12°20'E 18m MSL	378	12 May 76	11 48 54
	379	17 May 76	14 01 33
	391	26 Oct 76	13 27 37
	421	10 Aug 77	14 37 54
	422	11 Aug 77	11 57 48
	478	25 Sep 78	16 42 27
	479	26 Sep 78	13 16 47
Mildenhall, England 52°22'N 00°29'E 10m MSL	377	10 May 76	13 45 14
Lorient, France 47°46'N 03°33'W 52m MSL	398	2 Dec 76	14 45 37
	400	4 Dec 76	13 27 42
	401	5 Dec 76	14 51 04
	402	6 Dec 76	15 26 16
	410	4 Jul 77	15 04 52
	411	6 Jul 77	11 54 52

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, ★, whereas the flight track locations for the previously reported data are indicated by short solid lines *e.g.* near Birkhof.

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 multi-channel, multi-spectral nephelometer for the measurement of atmospheric total volume scattering coefficient and directional scattering functions,
- multi-spectral scanning radiometers for the measurement of sky and terrain radiances,
- a multi-spectral, two channel flat plate irradiator for the measurement of upwelling and downwelling irradiance levels, and
- meteorological transducers for the measurement of ambient temperature, dewpoint temperature and atmospheric pressure.

As noted in Johnson (1981a), 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 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, and is the subject of this report, the second in a two report series.

The general operating procedures employed during these APPROACH flight sequences were similar in nature to those described in each of the reports listed in Table 2.1. A few specific, but minor, variations in the procedure are discussed in the companion Winter-Summer report, Johnson (1981a).

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.

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 (SIG)	0	0	4	4	8
Lorient, France (LOR)	0	4*	3*	0	7
Memmingen, Germany (MEM)	0	0	3	6	9
Wunstorf, Germany (WUN)	3*	5*	13*	4	25
Soesterberg, Netherlands	1	0	0	0	1
Mildenhall, England (MIL)	4*	0	3	6	13
Vaerlose, Denmark (VAR)	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.

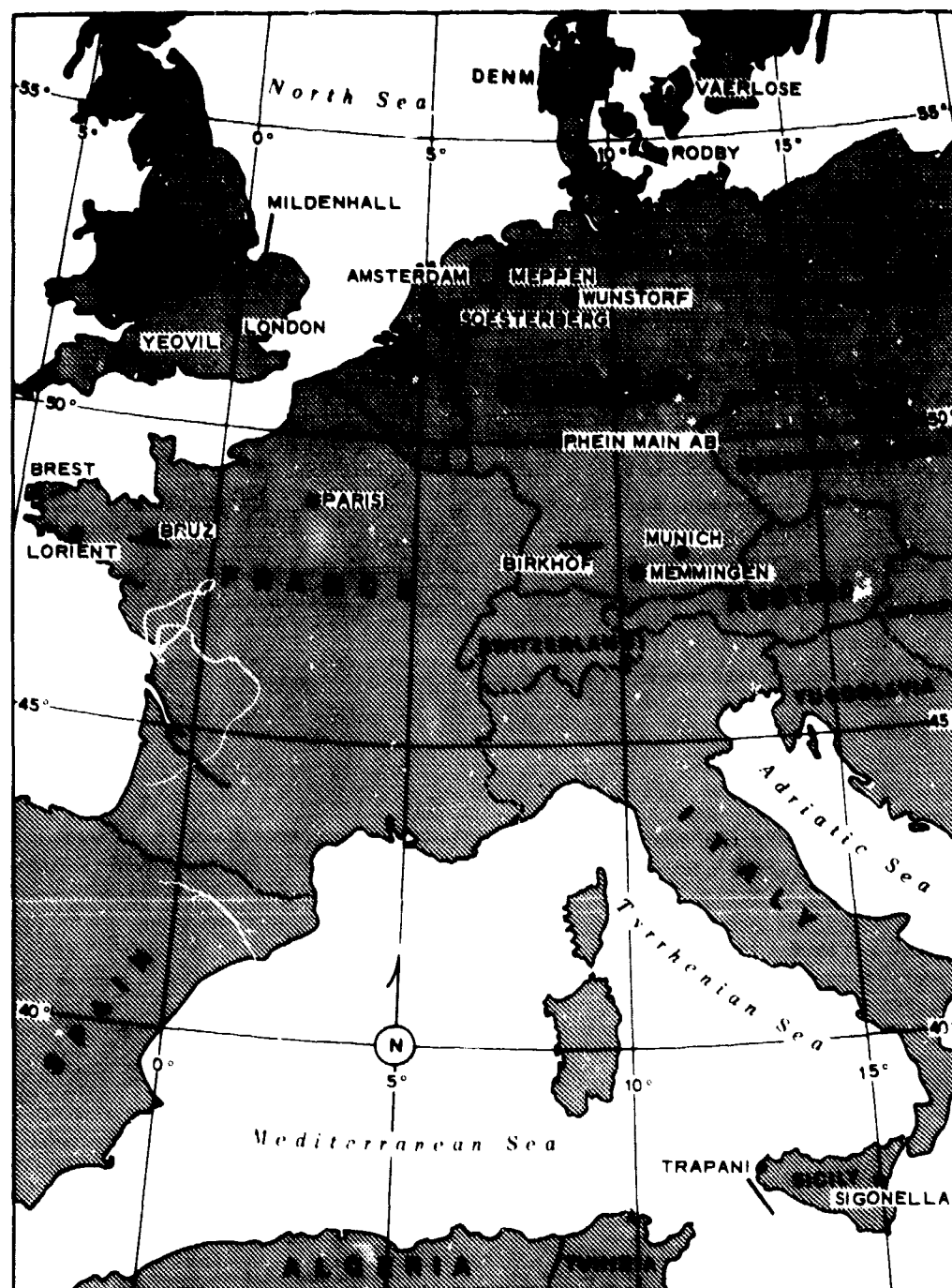


Fig. 2-1. Typical OPAQUE Flight Tracks.

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 pro-

vided by the U.S. Air Force Environmental Technical Applications Center (USAFETAC) 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 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 fifteen 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, although not as closely related as were the measurements during OPAQUE IV & V (Johnson, 1981a). The temperature data indicate a systematic difference of about 1°C between the C-130 and aerodrome measurements. The dewpoint and pressure measurements indicate substantially larger offsets.

There was an instrumentation failure in the dewpoint hygrometer system during flight C-399 (6 Dec 1976) that may have influenced the data during the immediately preceding OPAQUE II missions. Intermittent evidences of system failure were first noticed in the flight C-395 (19 Nov 1976) data, and were deleted during post-mission processing (Duntley *et al.*, 1977). However, a residual artifact of this system failure, and its subsequent repair may be evidenced in the data of Table 3.1. In an examination of the dewpoint differences, one notes that the differences associated with the OPAQUE I and II deployments, (flights 370 through 402) are all negative in sign and mostly small in magnitude. In contrast, the differences associated with the OPAQUE III deployment (flights 410 through 422) are all positive in sign and generally larger in magnitude. One may compare the data in Table 3.1 with the equivalent data presented previously in the companion Winter-Summer report, AFGL-TR-81-0154. In this comparison it appears that the

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)
Wunstorf	381	+0.6	-2.1	-1
	393	+1.5	-0.2	-3
	397	+0.8	-1.0	-4
	414	+1.4	+5.7	-4
	415	-1.5	+2.5	-4
	416	+2.3	+5.0	-5
	418	+1.4	+6.7	-7
Vaerlose	419	+1.8	+6.0	-5
	378	-0.9	-1.2	-4
	379	+0.1	-5.2	-6
	421	+0.8	+4.8	-5
Lorient	422	+0.6	+4.9	-10
	402	+0.8	MSG	-5
Mildenhall	410	+1.4	+1.4	-10
	377	+3.5	-1.5	1
Overall Average	15 flights	+1.0	OPQ I&II (7) -1.9 OPQ III (8) +4.6	-4.9

1. Δt is positive 14/16 cases, implying some systematic offset as also seen in the Winter-Summer data (Johnson, 1981a)
2. Δp is negative in all cases implying systematic offset and larger than Winter-Summer data.
3. Δdp is all neg. for OPQ I & II, but all pos. for OPQ III
Winter-Summer data: small and variable

measured differences, Δdp , are similar in sign and magnitude for the OPAQUE I, II, IV and V data, while the differences for the OPAQUE III set are systematically positive and large. There is no evidence of malfunction or calibration error associated with the dewpoint system during the OPAQUE III interval, so at this time the apparently anomalous behavior is unexplained.

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 Wunstorf, Germany Standard Meteorological Data Sheet Lat. 52°28'N Long. 09°25'E El. 57m

Spring 1976

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-381 Date: 25 May 1976								
1344	Cloud Data Unknown	11.2		14.0	7.0	-	1.0	Ceiling 5000 Feet

Table 3.2a (Con't.) Wunstorf, Germany

Fall 1976

Flight No. C-393 Date: 2 November 1976							
1144	2000	11.2		13.0	7.0	22	6.6
1244	2000	11.2		13.0	6.0	24	6.6
Flight No. C-394 Date: 18 November 1976							
1444	E400	1.7	F-	5.0	2.0	07	2.5 Sky Overcast Type Missing
Flight No. C-396 Date: 22 November 1976							
1144	Cloud Data Unknown	11.2	RW-	5.0	0.0	29	6.6
Flight No. C-397 Date: 23 November 1976							
1444	Cloud Data Unknown	11.2		2.0	0.0	28	6.6 Ceiling 2500 Feet Rain Shower During Past Hour

Summer 1977

Flight No. C-414 Date: 28 July 1977							
1144	Cloud Data Unknown	11.2		19.2	11.2	33	1.0 Ceiling 8000 Feet
Flight No. C-415 Date: 29 July 1977							
1244	Cloud Data Unknown	11.2		19.2	11.2	u	1.0 Ceiling 27000 Feet
Flight No. C-416 Date: 1 August 1977							
1644	Cloud Data Unknown	11.2		19.2	13.2	31	6.1 Ceiling Unlimited
Flight No. C-418 Date: 4 August 1977							
1044	Cloud Data Unknown	6.0	H	21.2	16.2	30	3.6 Ceiling Unlimited
Flight No. C-419 Date: 4 August 1977							
1644	Cloud Data Unknown	4.9	H	23.2	16.2	03	0.5 Ceiling Unlimited

Table 3.2b Vaerlose, Denmark Standard Meteorological Data Sheet Lat. 55°46'N Long. 12°20'E El. 18m

Spring 1976

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-378 Date: 12 May 1976								
1200	2500-0/0	40.0		13.0	5.0	16	7.2	
Flight No. C-379 Date: 17 May 1976								
1250	Cloud Data Unknown	11.2		16.0	5.0	12	2.5	1/8 Cover
1320	Cloud Data Unknown	11.2		17.0	4.0	09	1.5	1/8 Cover

Fall 1976

Flight No. C-391 Date: 26 October 1976								
1420	E190	7.0	F-			08	5.6	

Summer 1977

Flight No. C-421 Date: 10 August 1977								
1420	Cloud Data Unknown	11.2		21.2	14.2	15	4.1	Ceiling Unlimited
1450	Cloud Data Unknown	8.0	H	20.2	15.2	17	4.6	Ceiling Unlimited
Flight No. C-422 Date: 11 August 1977								
1150	Cloud Data Unknown	8.0	R-	19.2	16.2	01	2.5	Ceiling 8000 Feet
1200	Cloud Data Unknown	8.0	R-	19.2	16.2	01	2.1	Ceiling 8000 Feet

Summer 1978

Flight No. C-478 Date: 25 September 1978								
1650	Cloud Data Unknown	11.2	R-	13.2	8.2	24	7.2	Ceiling 8000 Feet
1750	Cloud Data Unknown	11.2		11.2	8.2	25	6.6	Ceiling Unlimited
Flight No. C-479 Date: 26 September 1978								
1250	Cloud Data Unknown	11.2		14.2	8.2	24	7.3	Ceiling 7000 Feet
1350	Cloud Data Unknown	11.2		14.2	8.2	23	7.2	Ceiling 9000 Feet

Table 3.2c Mildenhall, England Standard Meteorological Data Sheet Lat. 52°22'N Long. 00°29'E El. 10m

Spring 1976

Time GMT	Cloud Cover	Visibility (Kilometers)	Weather and Obstructions To Vision	Temp. (°C)	Dewpoint (°C)	Wind Direction (00-36)	Speed (mps)	Remarks
Flight No. C-377 Date: 10 May 1976								
1400	Cloud Data Unknown	6.0	H	18.0	11.0	33	6.6	Ceiling 2300 Feet

Table 3.2d Lorient, France Standard Meteorological Data Sheet Lat. 47°46'N Long. 03°33'E El. 52m

Fall 1976

Time GMT	Cloud Cover	Visibility (Kilometers)	Weather and Obstructions To Vision	Temp. (°C)	Dewpoint (°C)	Wind Direction (00-36)	Speed (mps)	Remarks
Flight No. C-398 Date: 2 December 1976								
1500	Cloud Data Unknown	8.0	RW-	8.0	6.0	32	6.6	
Flight No. C-400 Date: 4 December 1976								
1400	1500-0 E2300	11.2		7.0	3.0	30	4.1	
1500	1500-0 E2300	10.0		6.0	4.0	28	2.6	
Flight No. C-401 Date: 5 December 1976								
1400		11.2		9.0	4.0	22	3.6	
1500	2500-0/0	20.0		9.0	3.0	24	3.1	
Flight No. C-402 Date: 6 December 1976								
1500	Cloud Data Unknown	10.0		11.0	8.0	24	12.4	
1600	Cloud Data Unknown	11.2				24	13.3+	Gusts to 20.55

Summer 1977

Flight No. C-410 Date: 4 July 1977								
1500	3501200/0	5.0	TRW-	21.2	19.2	24	3.1	
Flight No. C-411 Date: 6 July 1977								
1200	3501200/0	5.0		26.2	19.2	06	3.6	

4. DATA PRESENTATION

4.1 Data and Flight Summary

During the Spring of 1976 (2 April through 26 May), thirteen flights were made in northern Europe, of which eight contained useable profile data. These data were reported in Duntley *et al.* (1977). Of these thirteen, four contained recoverable approach profiles. These four are listed in Table 1.1.

During the following fall (25 October through 6 December) thirteen additional flights were made in the same general areas, of which twelve contained useable profile data. These data were reported in Duntley *et al.* (1978a). Of these thirteen, ten contained recoverable approach data. These ten are also listed in Table 1.1.

During the following Summer of 1977 (4 July through 11 August) another thirteen flights were accomplished and subsequently reported in Duntley *et al.* (1978b). From this third set of flights, an additional nine contained recoverable approach data. These nine are listed in Table 1.1 as are two additional flights from the Summer of 1978 deployment (flights 478 & 479, 25 and 26 Sep 1978).

4.2 Description of Data Tables and Graphs

The flight data for the APPROACH sequences listed in Table 1.1 are presented both tabularly and graphically in

Figs. 4-1, 4-2 and 4-3. The spring, fall and summer measurements at each of four aerodromes appear grouped by location for ease of comparison.

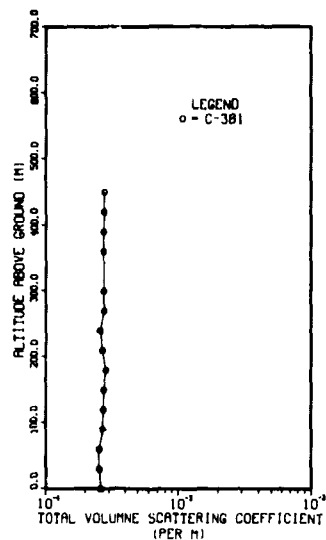
The scattering coefficient profiles represent measurements made continuously during each final descent which have been averaged vertically to yield one data point every 30 meters in altitude. The measurements were all made using a pseudo-photopic spectral response having a mean wavelength of 557 nm.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

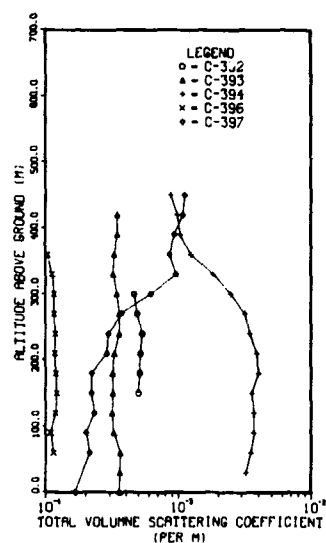
$$VR \approx 3/s$$

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 eleven of the twenty-six landing intervals, the meteorological report was truncated at 11.2 km (7 statute



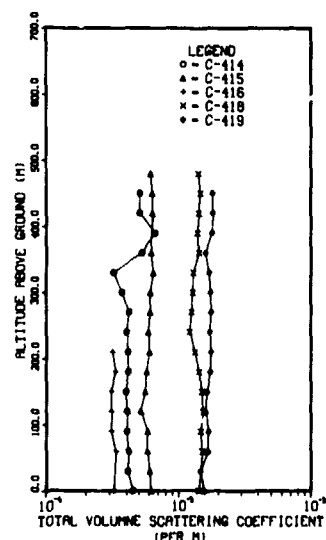
WUNSTORF, GERMANY SPRING 1976

Altitude (m) AGL	Total Volume Scattering Coefficient (m^{-1})				
	C381				
450	2.762E-04				
420	2.752E-04				
390	2.721E-04				
360	2.728E-04				
330	2.737E-04				
300	2.744E-04				
270	2.744E-04				
240	2.571E-04				
210	2.658E-04				
180	2.837E-04				
150	2.715E-04				
120	2.713E-04				
90	2.687E-04				
60	2.525E-04				
30	2.533E-04				
0	2.600E-04				
Reported Visibility (km)	≥ 11.2				
Visual Range (km)	11.5				
Illumination (lux)	55400				
Landing Time (GMT)	1428				



WUNSTORF, GERMANY FALL 1976

Altitude (m) AGL	Total Volume Scattering Coefficient (m^{-1})				
	C392	C393	C394	C396	C397
450			8.782E-04		1.120E-03
420		3.443E-04	9.862E-04		1.089E-03
390		3.459E-04	1.042E-03		9.347E-04
360		3.258E-04	1.244E-03	1.025E-04	8.595E-04
330		3.199E-04	1.847E-03	1.114E-04	9.645E-04
300	4.639E-04	3.394E-04	2.509E-03	1.147E-04	6.203E-04
270	4.927E-04	3.583E-04	3.225E-03	1.154E-04	3.734E-04
240	5.551E-04	3.545E-04	3.472E-03	1.175E-04	2.937E-04
210	5.230E-04	3.270E-04	3.914E-03	1.169E-04	2.871E-04
180	5.111E-04	3.162E-04	4.001E-03	1.182E-04	2.224E-04
150	5.024E-04	3.193E-04	3.598E-03	1.210E-04	2.224E-04
120		3.128E-04	3.716E-03	1.176E-04	2.325E-04
90		3.216E-04	3.721E-03	1.083E-04	2.023E-04
60		3.597E-04	3.524E-03	1.135E-04	2.147E-04
30		3.585E-04	3.260E-03		1.911E-04
0		3.555E-04			1.674E-04
Reported Visibility (km)	MSG	≥ 11.2	1.7	≥ 11.2	≥ 11.2
Visual Range (km)	6.0	8.3	9.1	26.5	18.0
Illumination (lux)	23500	32000	3100	11000	2300
Landing Time (GMT)	1323	1150	1358	1105	1410



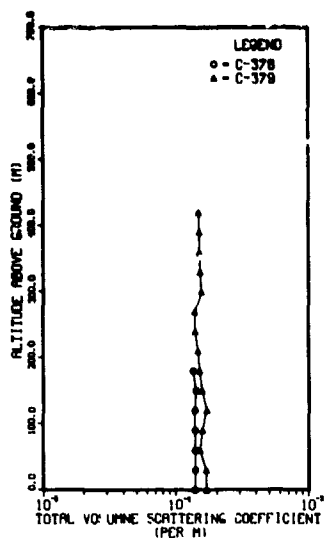
WUNSTORF, GERMANY SUMMER 1976

Altitude (m) AGL	Total Volume Scattering Coefficient (m^{-1})				
	C414	C415	C416	C418	C419
480		6.105E-04		1.397E-03	
450	5.065E-04	6.333E-04		1.452E-03	1.794E-03
420	5.105E-04	6.380E-04		1.421E-03	1.816E-03
390	6.640E-04	6.275E-04		1.385E-03	1.777E-03
360	5.250E-04	6.170E-04		1.414E-03	1.581E-03
330	3.186E-04	6.426E-04		1.289E-03	1.695E-03
300	3.696E-04	6.122E-04		1.281E-03	1.743E-03
270	4.167E-04	6.080E-04		1.247E-03	1.747E-03
240	3.999E-04	5.928E-04		1.213E-03	1.716E-03
210	4.082E-04	6.001E-04	3.139E-04	1.321E-03	1.744E-03
180	4.136E-04	5.736E-04	3.321E-04	1.429E-03	1.729E-03
150	3.930E-04	5.566E-04	3.072E-04	1.486E-03	1.632E-03
120	4.037E-04	5.141E-04	3.095E-04	1.527E-03	1.590E-03
90	4.004E-04	5.798E-04	3.074E-04	1.456E-03	1.648E-03
60	4.130E-04	5.771E-04	3.308E-04	1.497E-03	1.651E-03
30	4.064E-04	6.033E-04	3.368E-04	1.440E-03	1.440E-03
0	4.480E-04	6.196E-04	3.223E-04	1.422E-03	1.569E-03
Reported Visibility (km)	≥ 11.2	≥ 11.2	≥ 11.2	6.0	4.9
Visual Range (km)	6.7	4.8	9.4	2.1	1.9
Illumination (lux)	49300	58800	34200	53600	22000
Landing Time (GMT)	1159	1240	1536	1046	1647

Graphic

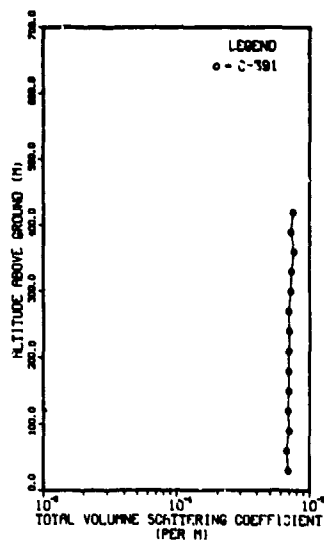
Tabular

Fig. 4-1. APPROACH Profiles - Wunstorf, Germany.



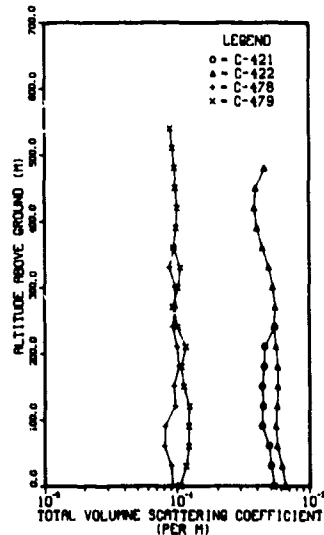
VAERLORE, DENMARK SPRING 1976

Altitude (m) AGL	Total Volume Scattering Coefficient (m^{-1})			
	C378	C379		
420		1.495E-04		
390		1.509E-04		
360		1.501E-04		
330		1.520E-04		
300		1.546E-04		
270		1.593E-04		
240		1.406E-04		
210		1.463E-04		
180	1.353E-04	1.510E-04		
150	1.412E-04	1.571E-04		
120	1.387E-04	1.700E-04		
90	1.402E-04	1.587E-04		
60	1.396E-04	1.512E-04		
30	1.398E-04	1.480E-04		
0	1.398E-04	1.480E-04		
Reported Visibility (km)	40.0	>11.2		
Visual Range (km)	21.6	17.8		
Illumination (lux)	70100	51000		
Landing Time (GMT)	1148	1401		



VAERLORE, DENMARK FALL 1976

Altitude (m) AGL	Total Volume Scattering Coefficient (m^{-1})			
	C391			
420	7.480E-04			
390	7.159E-04			
360	7.625E-04			
330	7.267E-04			
300	7.181E-04			
270	6.910E-04			
240	6.982E-04			
210	6.940E-04			
180	6.937E-04			
150	6.912E-04			
120	6.879E-04			
90	6.958E-04			
60	6.708E-04			
30	6.851E-04			
0				
Reported Visibility (km)	7.0			
Visual Range (km)	4.3			
Illumination (lux)	6200			
Landing Time (GMT)	1327			



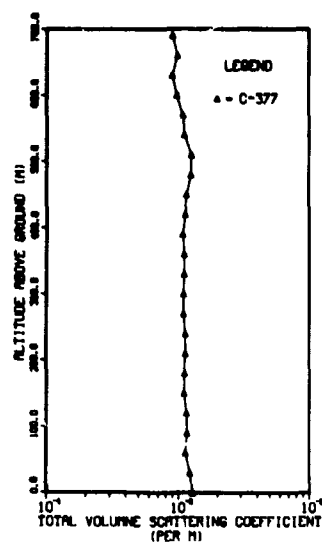
VAERLORE, DENMARK SUMMER 1977 & 1978

Altitude (m) AGL	Total Volume Scattering Coefficient (m^{-1})			
	C421	C422	C478	C479
540				8.919E-05
510				9.235E-05
480		4.530E-04		9.521E-05
450		3.937E-04		9.738E-05
420		3.848E-04		1.002E-04
390		4.017E-04		9.823E-05
360		4.390E-04	9.491E-05	9.373E-05
330		4.864E-04	8.738E-05	1.049E-04
300		5.240E-04	9.683E-05	1.017E-04
270		5.468E-04	9.737E-05	9.347E-05
240	5.432E-04	5.322E-04	9.300E-05	1.009E-04
210	4.569E-04	5.352E-04	9.983E-05	1.159E-04
180	4.517E-04	5.670E-04	1.028E-04	1.067E-04
150	4.355E-04	5.684E-04	9.400E-05	1.114E-04
120	4.416E-04	5.613E-04	9.638E-05	1.224E-04
90	4.376E-04	5.549E-04	8.177E-05	1.210E-04
60	4.908E-04	5.654E-04	8.062E-05	1.217E-04
30	5.073E-04	6.148E-04	9.052E-05	1.158E-04
0	5.350E-04	6.526E-04	9.193E-05	1.042E-04
Reported Visibility (km)	8.0	8.0	>11.2	>11.2
Visual Range (km)	5.6	4.6	32.6	28.8
Illumination (lux)	34800	17700	1300	21000
Landing Time (GMT)	1437	1157	1642	1316

Graphic

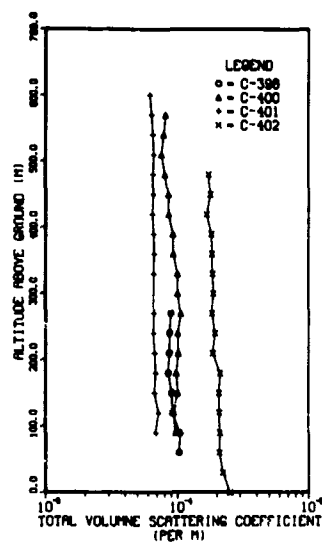
Tabular

Fig. 4-2. APPROACH Profiles - Vaerlose, Denmark.



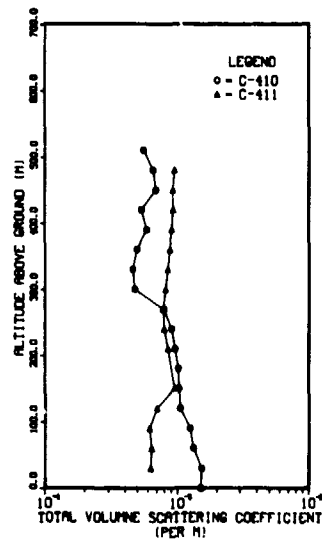
MILDENHALL, ENGLAND SPRING 1976

Altitude (m) AGL	Total Volume Scattering Coefficient (m^{-1})			
	C377			
690	8.893E-04			
660	9.893E-04			
630	8.874E-04			
600	9.465E-04			
570	1.040E-03			
540	1.094E-03			
510	1.239E-03			
480	1.232E-03			
450	1.141E-03			
420	1.110E-03			
390	1.049E-03			
360	1.097E-03			
330	1.093E-03			
300	1.000E-03			
270	1.000E-03			
240	1.126E-03			
210	1.127E-03			
180	1.122E-03			
150	1.096E-03			
120	1.147E-03			
90	1.160E-03			
60	1.130E-03			
30	1.228E-03			
0	1.272E-03			
Reported Visibility (km)	6.0			
Visual Range (km)	2.4			
Illumination (lux)	12000			
Landing Time (GMT)	1345			



LORIENT, FRANCE FALL 1976

Altitude (m) AGL	Total Volume Scattering Coefficient (m^{-1})			
	C398	C400	C401	C402
600			6.149E-05	
570		8.091E-05	6.342E-05	
540		7.839E-05	6.409E-05	
510		7.543E-05	6.610E-05	
480		8.013E-05	6.520E-05	1.718E-04
450		8.474E-05	6.516E-05	1.799E-04
420		8.518E-05	6.419E-05	1.645E-04
390		9.175E-05	6.543E-05	1.801E-04
360		9.242E-05	6.648E-05	1.820E-04
330		9.933E-05	6.600E-05	1.840E-04
300		1.000E-04	6.593E-05	1.876E-04
270	8.839E-05	1.047E-04	6.585E-05	1.813E-04
240	8.656E-05	9.937E-05	6.522E-05	1.919E-04
210	8.636E-05	1.005E-04	6.478E-05	1.839E-04
180	8.470E-05	9.744E-05	6.827E-05	2.106E-04
150	9.019E-05	1.001E-04	6.686E-05	2.064E-04
120	9.157E-05	9.356E-05	7.173E-05	2.078E-04
90	1.031E-04	9.611E-05	6.822E-05	2.096E-04
60	1.020E-04			2.074E-04
30				2.218E-04
0				2.517E-04
Reported Visibility (km)	8.0	>11.2	>11.2	10
Visual Range (km)	29.4	31.2	44.1	12.0
Illumination (lux)	2300	30900	11200	1500
Landing Time (GMT)	1445	1337	1451	1526



LORIENT, FRANCE SUMMER 1976

Altitude (m) AGL	Total Volume Scattering Coefficient (m^{-1})			
	C410	C411		
510	5.561E-04	9.503E-04		
480	6.541E-04	9.252E-04		
450	6.883E-04	9.280E-04		
420	5.370E-04	9.059E-04		
390	5.899E-04	8.743E-04		
360	4.923E-04	8.402E-04		
330	4.586E-04	8.115E-04		
300	4.753E-04	7.776E-04		
270	7.857E-04	8.469E-04		
240	9.024E-04	8.995E-04		
210	9.583E-04	8.996E-04		
180	1.013E-03	8.996E-04		
150	1.026E-03	6.194E-04		
120	1.038E-03	6.401E-04		
90	1.236E-03	6.263E-04		
60	1.317E-03			
30	1.521E-03			
0	1.497E-03			
Reported Visibility (km)	5.0	5.0		
Visual Range (km)	2.0	4.8		
Illumination (lux)	4600	67000		
Landing Time (GMT)	1504	1154		

Graphic

Tabular

Fig. 4-3. APPROACH Profiles - Mildenhall, England & Lorient, France.

miles) i.e. $VV > 11.2$ km was reported as 11.2 km. This common aeronautical practice precluded the accumulation of as large a comparative data base as was desired, however there are seventeen instances of reasonable simultaneity that may be representative of the overall comparison listed in Table 5.2. The reported visual estimates are also 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 1.1. 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 1.1 and truncated to hours and minutes only.

5. DATA DISCUSSION

As noted in the introductory remarks of section 1 in both this report and its Winter-Summer companion, Johnson, 1981a, 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, in addition to that presented in Johnson, 1981a, 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-five scattering coefficient profiles illustrated in Section 4, only four, two in the Fall and two in the Summer seasons show marked structure within the low level haze. Thus, as summarized in Table 5.1, there are only seven flights out of the total fifty-one reported in these two companion reports which illustrate clearly discernible variations in the magnitude of the near surface haze profile.

There were twelve instances within the twenty-five landing episodes where the station visibility was reported as less than 11.2 km and therefore could be approximated by the derived value of visual range ($VR = 3/s$) as discussed in Section 3. These twelve values plus the five available from the companion Winter-Summer report are summarized in Table 5.2 and illustrated in Fig. 5-1. The data points for two flights 378/VAR and 398/LOR have been omitted from the graphical display since they are substantially beyond the scale of the plot at visual ranges greater than 20 km. Whereas one might expect better comparisons between these pseudo-simultaneous determinations, there are good and sufficient reasons to anticipate a fair degree of spread within this small uncontrolled sample. Johnson (1981b). The trend in the comparison is reasonable for the most part, although the data tend to illustrate clearer derived values than those reported by station observers.

As an artifact of the site-season mix within the overall data set, only the Wunstorf site has a substantial

Table 5.1.

Summary of Conditions for Flights Profiles Illustrating Low Altitude Haze Structure

FLT NO/STA	Season	Surface Scat Coef (m^{-1})	Haze Top Altitude (m AGL)	Wind Direction-Speed (deg) - msec^{-1}	Obstructions to Vision	Dewpoint Depression	
						STA (°C)	C-130 (°C)
435/MEM	Winter	2.6 E-4	100	180 - 3.6	-	6	8.1
436/MEM	Winter	3.8 E-4	150	060 - 2.5	-	8	6.2
439/MEM	Winter	6.4 E-4	100	030 - 1.5	H	5	7.2
394/WUN	Fall	3.3 E-3	350	070 - 2.5	F-	3	0.7**
397/WUN*	Fall	1.7 E-4	350	280 - 6.6	RW	2	0.2**
410/LOR	Summer	1.5 E-3	300	240 - 3.1	TRW-	2	2.0
411/LOR*	Summer	6.3 E-4	150	060 - 3.6	-	7	7.9

* Haziness increasing with increasing altitude.

** CAM-137 Dewpoint Hygrometer failed during the OPAQUE II deployment, and examination of the dewpoint temperature measurements indicates the high probability of an amplifier offset equivalent to approximately 2°C during the interval preceeding the failure. These indicated dewpoint depressions therefore may be too small.

Table 5.2.
Comparison of Station Reported Visibilities
and Nephelometer Derived Visual Ranges

FLT NO/STA	Season	Reported Visibility (km)	Derived Visual Range (km)
394/WUN	Fall '76	1.7	0.9
418/WUN	Summer '77	6.0	2.1
419/WUN	Summer '77	4.9	1.9
456/WUN	Winter '78	2.5	2
378/VAR	Fall '76	40	21.6
391/VAR	Fall '76	7.0	4.3
421/VAR	Summer '77	8.0	5.6
422/VAR	Summer '77	8.0	4.6
398/LOR	Fall '76	8.0	29.4
402/LOR	Fall '76	10	12.0
410/LOR	Summer '77	5.0	2.0
411/LOR	Summer '77	5.0	4.8
460/SIG	Summer '78	5	12
461/SIG	Summer '78	8	13
377/MIL	Spring '76	6.0	2.4
475/MIL	Summer '78	11	13
439/MEM	Winter '78	5	5

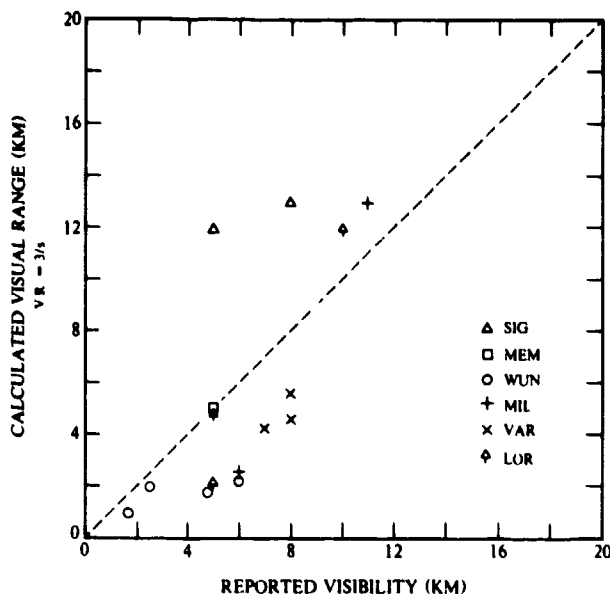


Fig. 5-1. Comparison of reported visibilities and derived visual ranges.

number of profiles appearing in both of these two companion reports. Thus, an enlarged comment upon the possibility of a higher seasonal variation in scattering coefficient existing during the Winter, as indicated in the Winter-Summer report, is probably not justified. Within the composite nineteen flight Wunstorf set; 4 Winter, 1978, 4 Summer 1978, 6 Spring and Fall 1976, and 5 Summer 1977; there does not seem to be any significant difference in the degree of scattering coefficient variation as a function of season. There is however a broad spread in the range of values encountered, as one might well expect, and in all but two of these nineteen instances, the

profiles are remarkably constant within this near surface regime. As noted in the previous Winter-Summer report, these data by and large represent midday measurements and thus are based in favor of good convective mixing induced by solar heating of the ground surface.

5.1 Summary

Twenty-five vertical profiles of the photopic atmospheric volume scattering coefficient representing Spring, Fall 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-one out of twenty-five instances, the profile is essentially constant in value and thus the modelling approach proposed by Hering (1981) is in fact an appropriate procedure.

When combined with the data from the companion Winter-Summer data set, Johnson (1981a), forty-seven out of fifty-four (87%) of the profiles are represented by stable, nearly constant values of scattering coefficient within this very low altitude regime.

The identification of the conditions resulting in the seven profiles showing variations within their vertical structure will require additional analysis. A supplementary set of precision local meteorological observations including local trajectories would be beneficial.

6. ACKNOWLEDGEMENTS

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METEOROLOGICAL GLOSSARY AND ABBREVIATIONS

SKY AND CEILING	VISIBILITY (VV)																								
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	Reported in kilometers. WEATHER AND OBSTRUCTION TO VISION SYMBOLS <table> <tr> <td>A Hail</td><td>IF Ice fog</td></tr> <tr> <td>AP Snail hail</td><td>K Smoke</td></tr> <tr> <td>BD Blowing dust</td><td>L Drizzle</td></tr> <tr> <td>BN Blowing sand</td><td>R Rain</td></tr> <tr> <td>BS Blowing snow</td><td>RW Rain showers</td></tr> <tr> <td>D Dust</td><td>S Snow</td></tr> <tr> <td>E Sleet</td><td>SG Snow grains</td></tr> <tr> <td>EW Sleet showers</td><td>SP Snow pellets</td></tr> <tr> <td>F Fog</td><td>SW Snow showers</td></tr> <tr> <td>GF Ground fog</td><td>T Thunderstorms</td></tr> <tr> <td>H Haze</td><td>ZL Freezing drizzle</td></tr> <tr> <td>IC Ice crystals</td><td>ZR Freezing rain</td></tr> </table>	A Hail	IF Ice fog	AP Snail 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
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	CLOUD ABBREVIATIONS <table> <tr> <td>Ac Altocumulus</td><td>Cs Cirrostratus</td></tr> <tr> <td>As Altostratus</td><td>Cu Cumulus</td></tr> <tr> <td>Cb Cumulonimbus</td><td>Ns Nimbostratus</td></tr> <tr> <td>Cc Cirrocumulus</td><td>Sc Stratocumulus</td></tr> <tr> <td>Ci Cirrus</td><td>St Stratus</td></tr> </table> 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.	Ac Altocumulus	Cs Cirrostratus	As Altostratus	Cu Cumulus	Cb Cumulonimbus	Ns Nimbostratus	Cc Cirrocumulus	Sc Stratocumulus	Ci Cirrus	St Stratus														
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RELATIVE HUMIDITY (RH) Reported in percent and computed from temperature and dewpoint.	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.
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