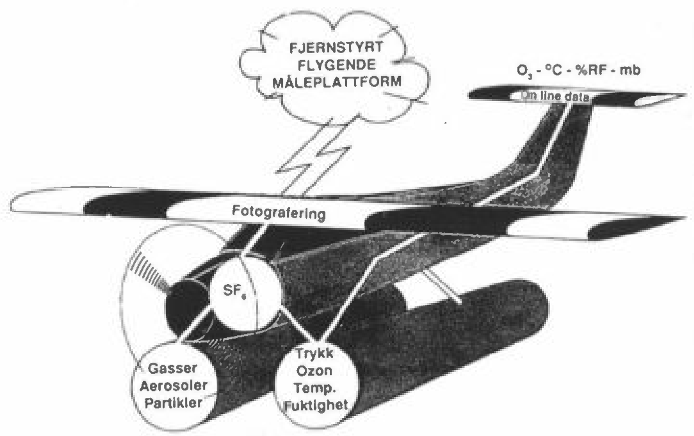
NILU TR: 10/90

NILU TR : 10/90
REFERANSE :E-90007
DATO : NOVEMBER 1990
ISBN : 82-425-0215-3

BRUK AV FJERNSTYRTE FLY

S. Larsen



NILU
NORSK INSTITUTT FOR LUFTFORSKNING
Norwegian Institute For Air Research
POSTBOKS 64 — N-2001 LILLESTRØM — NORWAY

FORORD

Denne rapporten er utarbeidet for NILU som grunnlag for vurdering av bruk av fjernstyrte fly i luftkvalitetsundersøkelser.

Jeg vil rette en stor takk til følgende instanser og personer for den entusiasme, god støtte og gode råd som jeg har mottatt under arbeidet med dette forprosjektet:

- Forsvarets Drone-team i Fredrikstad
  v/Kpt. Lauritsen og Fenr. Heidal - TEK-KEM
  v/Poju R. Stephansen og Carl Erik Staphansen
- National Power
  v/Steve Sutton og Tony Fuller

For øvrig vil jeg rette en takk til kolleger ved NILU som har bidratt med faglig veiledning og annen støtte.

SAMMENDRAG

Forskningsinstitutter i flere land har i de senere år tatt i bruk fjernstyrte fly til bl.a. meteorologiske målinger og prøvetaking i forbindelse med luftforurensninger.

For å undersøke andre brukeres erfaringer på området, og for å vurdere om denne teknikken vil kunne anvendes ved NILU, ble det opprettet et internt forprosjekt i 1990.

Denne rapporten beskriver hva som er kommet frem av informasjon gjennom litteraturstudier og innhentede opplysninger fra besøk og konsultasjoner med andre brukere.

Rapporten inneholder opplysninger om flytyper og styringssystemer, anvendelsesområder, måle- og prøvetakerutstyr. Formaliteter knyttet til anvendelse av fjernstyrte fly er også belyst.

Konklusjonen er:

- Det er fullt mulig å anvende fjernstyrte fly som plattform til målinger og prøvetakinger.

- Det vil gi NILU mulighet til å måle i et område og et luftsjikt der vi i dag ikke måler.

- Bruk av fjernstyrte fly vil være den mest effektive og økonomiske måte å utføre slike målinger på.

INNHOLD

BRUK AV FJERNSTYRTE FLY

1 INNLEDNING

Da Brian Lamb (stipendiat fra Idaho, USA) i 1978 introduserte SF_6 sporstoffteknikk ved NILU, ble det reist spørsmål om muligheten for å anvende fjernstyrte fly til prøvetaking, spesielt for å kartlegge vertikalspredning.

Det ble vist til en rapport med engelske/franske erfaringer fra bruk av slike fly til meteorologiske målinger. I samme rapport ble det vurdert muligheter for å utstyre flyene med forskjellige typer prøvetakerutstyr.

Det har siden den gang skjedd en stor utvikling på dette området.

Fjernstyringsutstyr er blitt meget avansert og pålitelig. Nytt utstyr til navigasjon, måle- og prøvetaking er blitt utviklet spesielt for bruk i fjernstyrte fly. Utstyret er kommersielt tilgjengelig og kan leveres på bestilling.

Forskningsinstitutter i flere land har i de senere år tatt i bruk fjernstyrte fly til meteorologiske målinger og til prøvetaking i forbindelse med luftforurensninger. Dette er bakgrunnen for at saken er tatt opp til ny vurdering ved NILU.

1.1 MÅLSETTING

Prosjektet har vært gjennomført i løpet av 1990 og hatt følgende målsetting:

- Innhente opplysninger om andre brukeres erfaring

- Vurdere flytyper og styringssystemer

- Vurdere instrumenter
  - måleutstyr
  - prøvetakere
  - måledatabehandlingsutstyr

- Skaffe oversikt over nødvendige formaliteter

- Innhente opplysninger om tilgjengelighet og kostnader på nødvendig utstyr for eventuelle anskaffelser

- Kartlegge mulige anvendelsesområder av interesse for NILU

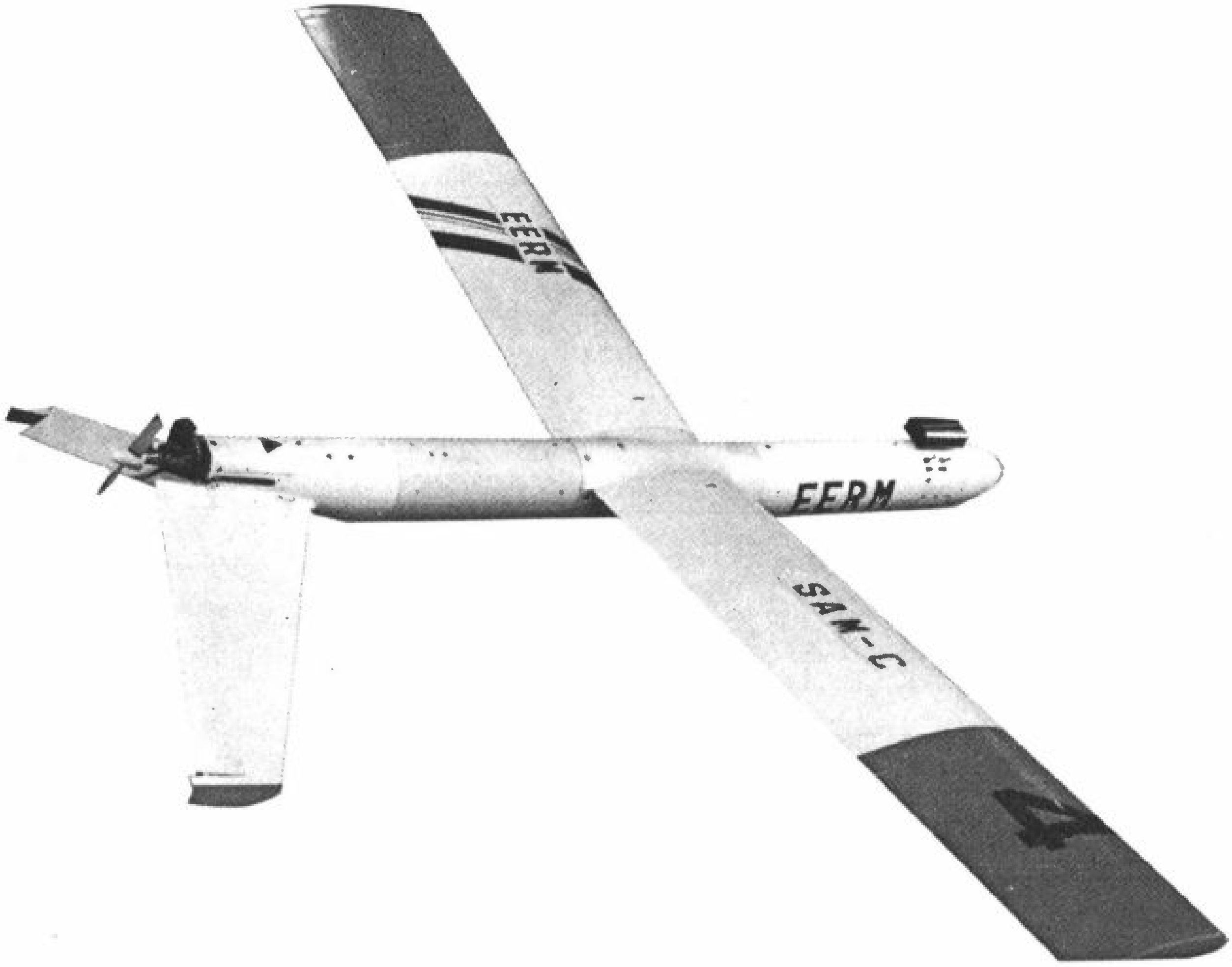
2 LITTERATURSTUDIER OG KONTAKTER

2.1 FRANSK INSTITUTT FOR METEOROLOGISK FORSKNING (ETABLISSEMENT D'ETUDES ET DE RECHERCHES MÉTÉOROLOGIQUE (EERM)

Som vist av Horcica, V. (1980), har EERM anvendt fjernstyrte fly siden 1978. De har utviklet spesielle flytyper til sine formål, se fig. 1.

Videre anvender de fly i tillegg til og ofte i steden for ballong til stabilitetsmålinger (radiosondemålinger). Bruk av fly er vurdert som bedre egnet og mer fleksibelt under varierende værforhold enn bruk av ballong. Kostnadsmessig kommer også fly bedre ut.

EERM anvender også fjernstyrte fly som plattform til målinger/prøvetakinger av gasser, aerosoler, støv og partikler. De utstyrer da flyene med en pumpe og dertil egnete filtere i spesielle filterholdere.



Figur 1: EERMs fjernstyrte fly, en SAM-C, av hensyn til prøvetakingen er motoren her plassert i halen på flyet.

2.2 NATIONAL POWER (NP), TIDLIGERE CERL

NP har anvendt fjernstyrte fly til målinger/prøvetakinger siden 1977. Under benevnelsen Weather and Atmospheric Sampling Platform (WASP), som vist av Ames, D.L. (1981), har de utviklet spesielle fly og måleinstrument til dette formål, se fig. 2.

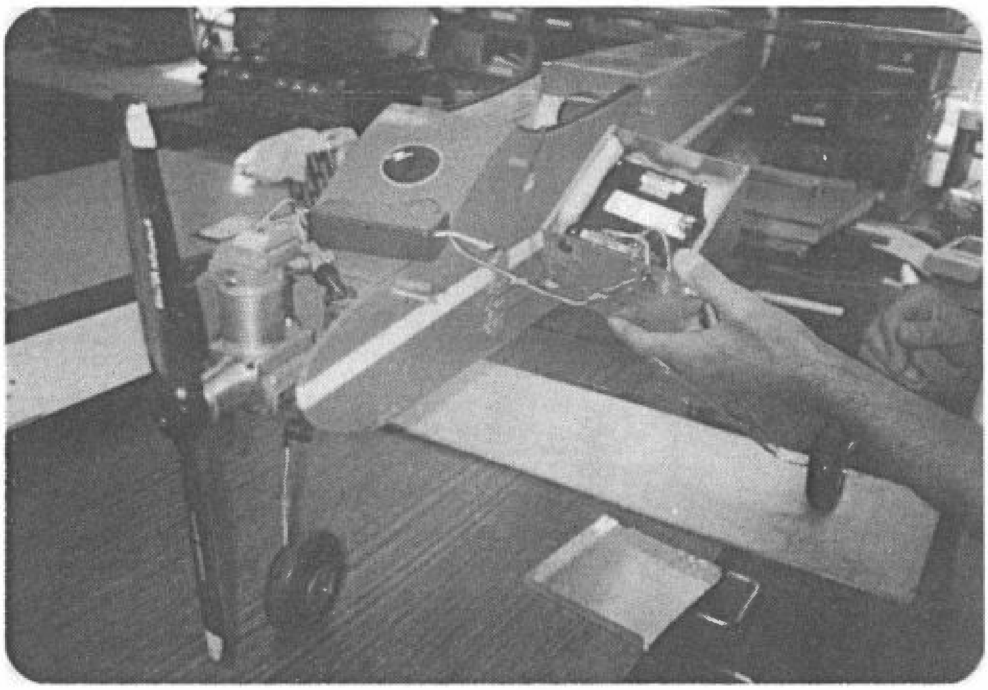
Flyene blir i stor grad brukt i forbindelse med målinger og prøvetakinger i nærområdene rundt kraftverk. NP har utstyrt flyene for å kunne utføre flere typer oppdrag, som:

- Målinger av vertikalprofiler opp til ca 1000 meter av:
  - temperatur
  - fuktighet
  - lufttrykk
  - ozon (verifisering av bakkestasjoner)

- Prøvetaking av gasser, aerosoler, støv og partikler

- Luftfotografering, også IR

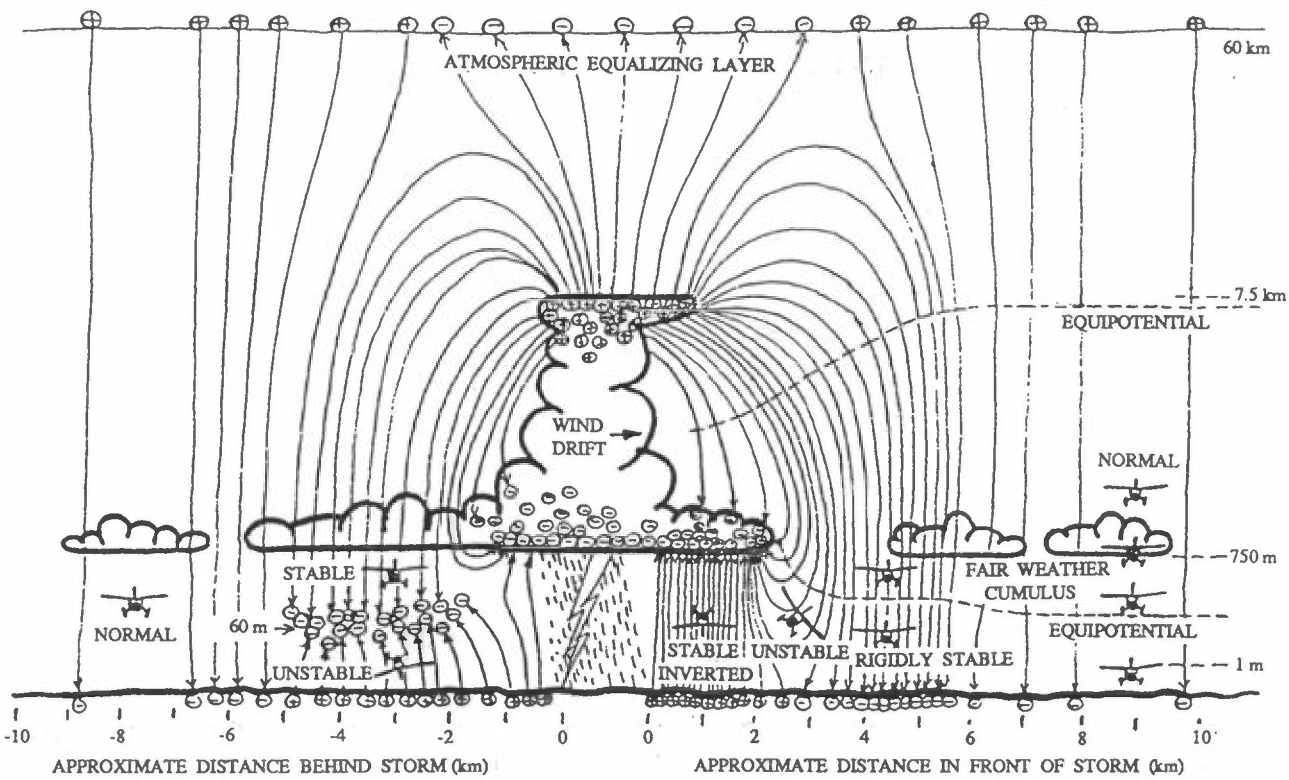
NP har utført mange vellykkede målinger med dette utstyret. For det meste i England, men også i forbindelse med målekampanjer i samarbeidsprosjekt med Belgia, Frankrike og Italia, se for øvrig Vedlegg 1.



Figur 2: Bildet viser NPs WASP III, som brukes til målinger av vertikalprofiler.

2.3 APPLIED PHYSICS LABORATORY, JOHNS. HOPKINS UNIVERSITY LAUREL, MARYLAND, USA

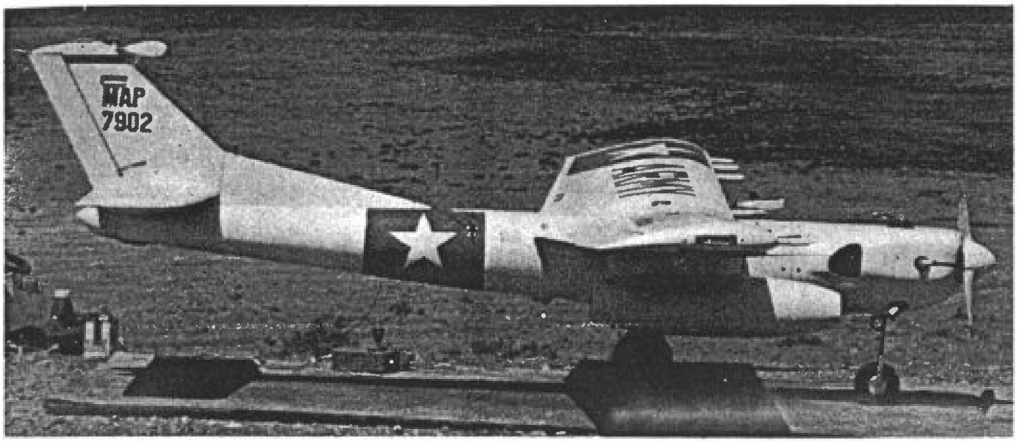
Ved Johns. Hopkins University Laurel, har de som vist av Hill, M.L. (1984) anvendt fjernstyrte fly i forbindelse med meteorologiske og fysiske målinger i forskningsprosjekter. Undersøkte ting er er studier av atmosfærens elektriske felt og variasjoner i dette, spesielt ved tordenværpassasjer, se fig.3.



Figur 3: Figuren viser de elektriske felt i og rundt et tordenvær og hvordan disse påvirker flyets autopilot.

2.4 APPLIED PHYSICS LABORATORY, UNIVERSITY OF TEXAS, EL PASO, USA

Under benevnelsen Maneuverable Atmospheric Probe (MAP), som vist av McDonald, C. et al. (1984), har de spesialutviklet et fjernstyrt fly som brukes til forskjellige typer målinger, se fig. 4. Flyet er mest brukt til måling og kartlegging av atmosfæriske prosesser, som vil kunne ha effekt på egenskapene til elektro-optisk måleutstyr. Flyet er bl.a. utstyrt med et lite og kompakt foroverrettet totallysspredings nephelometer, filterholdere og en radiosonde.



Figur 4: Bildet viser et fjernstyrt fly for måling og prøvetaking i atmosfæren (MAP/UV 8001).

2.5 ISRAEL AIRCRAFT INDUSTRI, SOREQ NUCLEAR RESEARCH CENTER OG GEOLOGICAL SURVEY OF ISRAEL

En avansert drone er utviklet for overvåking av miljø- og geofysiske fenomener, se fig. 5.

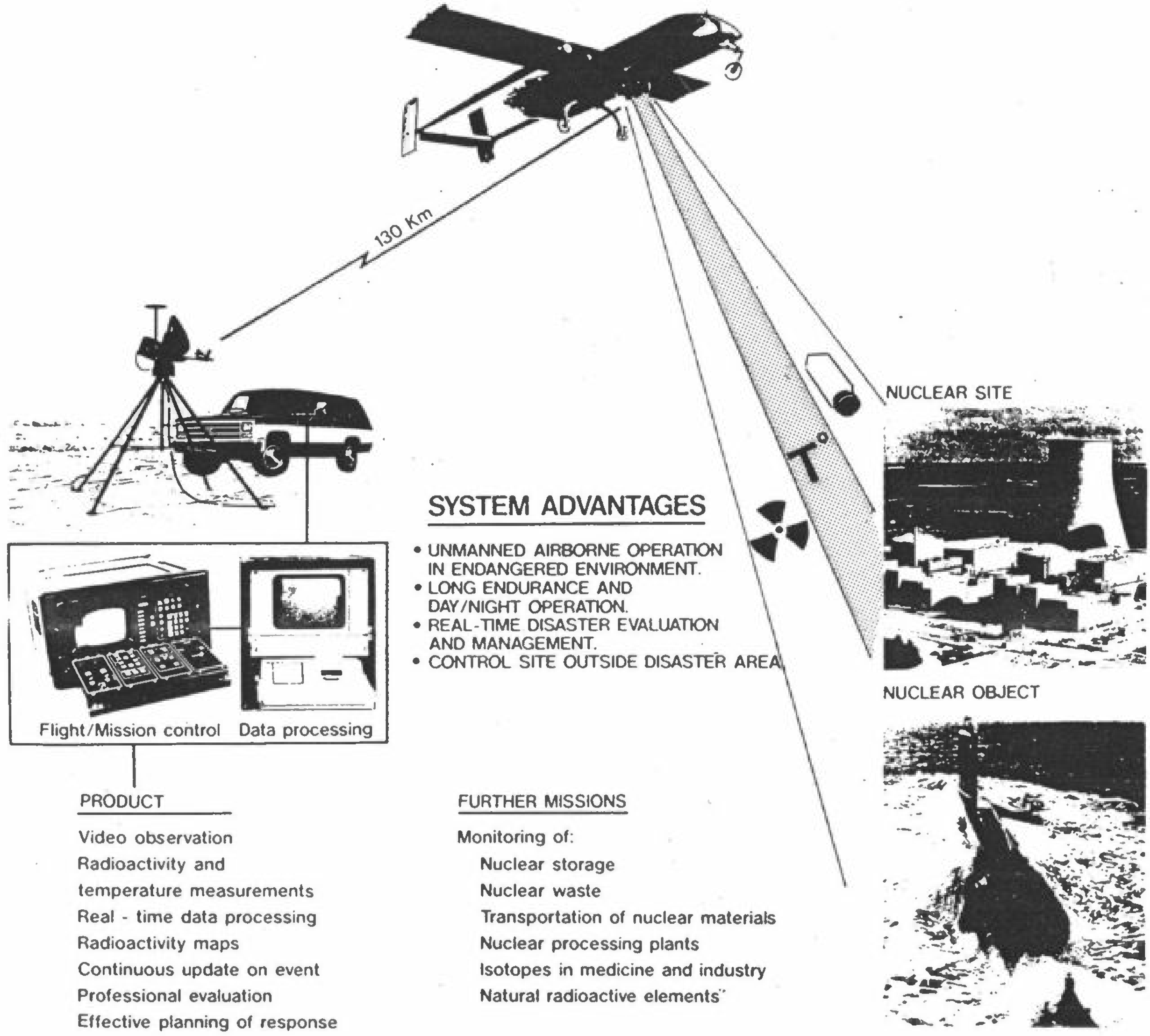
Dronesystemet omfatter

- "Real-time" måling av
  - radioaktive strålingsnivå av forskjellige radioaktive isotoper (eks. T131, M099, Zr95, Te132, Cs134 og Cs137)
  - variasjoner mellom kilden på bakken og konsentrasjonen i atmosfæren
  - vindhastighet og vindretning ved og omkring et evt. ulykkessted samt temperaturmåling og kartlegging av temperatur ved hjelp av IR-kamera.

- Utstyret kan brukes til å følge eventuelle radioaktive skyer, gasser og partikler
- Kartlegging av hvordan spredning utvikler seg (med høy oppløsning)
- Visuell observasjon av evt. ulykkeskilde på avstand/høyde opp mot 5 km ved hjelp av et avansert TV-kamera med stor zoomkapasitet.

Dronen fjernstyres fra en mobil kontrollenhet som kan plasseres på god avstand fra ulykkesområdet. Dette er mulig pga stor operasjonsradius (130 km) og lang flytid (5-6 timer). Dronen kan operere i all slags vær, dag som natt.

Et slikt system med "real-time data acquisition" og "on-line processing", som vist av Zafir, H. et al. (1990), er også tenkt som hjelpeverktøy for overvåking, kartlegging og planlegging av evakuerings- og redningsaksjoner ved eksempelvis en atomulykke.



Figur 5: Figuren viser et fjernstyrt fly for "real-time" måling av radioaktiv stråling.

4 FLYTYPER OG UTSTYR

Utviklingen av fjernstyrte fly (droner/unmanned aerial vehicles/remotely piloted vehicles) har gjennomgått en sterk utvikling de senere år. Ny byggeteknikk med moderne materialer, såkalt "COMPOSITE-teknikk" har kommet for fullt på dette området, slik at flyenes styrke/vektforhold er vesentlig forbedret.

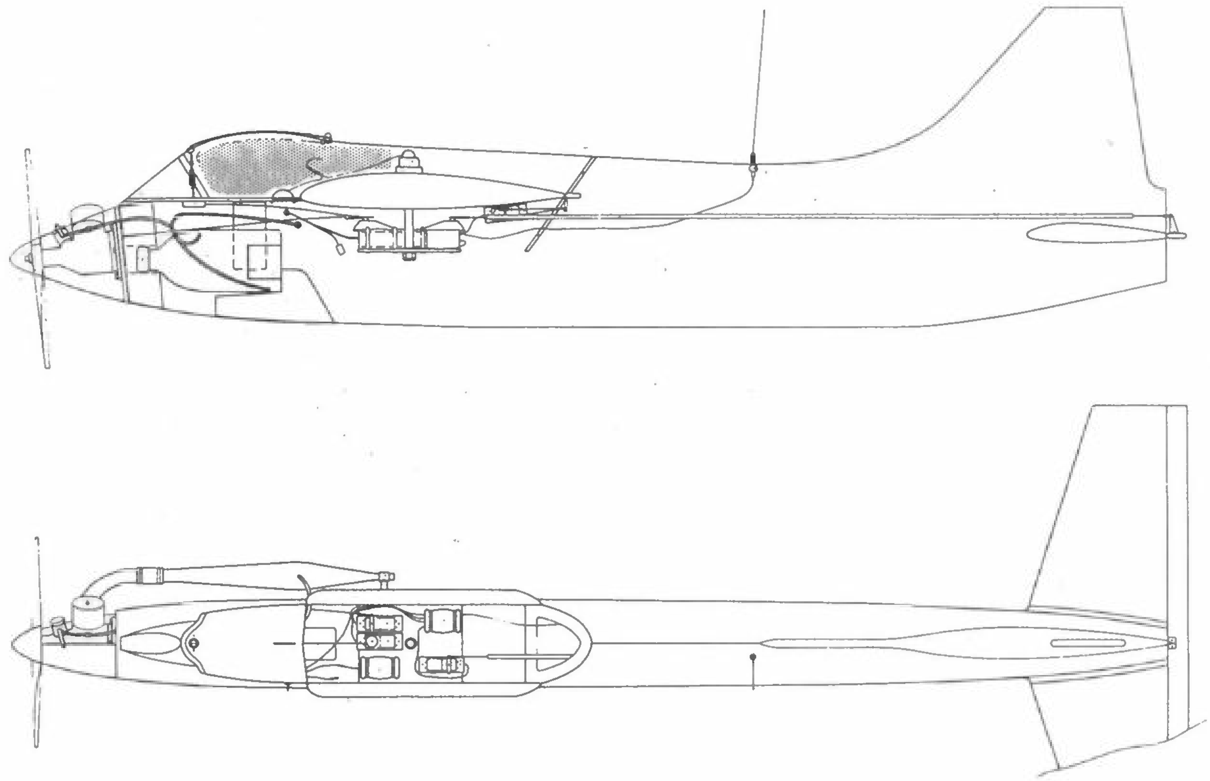
Dette sammen med nye, større og mer pålitelige motorer, har ført til at flyene kan ta med større nyttelast enn tidligere. Flytypene som anvendes, varierer fra rimelige modifiserte radiofjernstyrte modellfly, til mer kostbare avanserte datastyrte fly med programmerbare autopiloter, som styres via datalink på bakken, ombord i skip eller fly.

De enkleste flyene, se fig. 6 og 7, kan ta en nyttelast på ca 2 kg, har en flytid på ca 30-40 min og har normalt en aksjonsradius innenfor det visuelle felt, som er ca 1 km. De mer avanserte versjonene kan ta med vesentlig mer nyttelast, ca 20-30 kg, kan holdes i luften i opp til 5-6 timer. Disse kan ha en aksjonsradius på opp til 130 km og kan flys/anvendes i alt slags vær, dag som natt.

Mellom disse ytterlighetene kan det tilpasses løsninger etter behov og økonomi.

Mulighetene for å anvende slike fly til målinger og prøvetakinger er omfattende dersom behovet er til stede. Begrensningene ligger i egen fantasi.

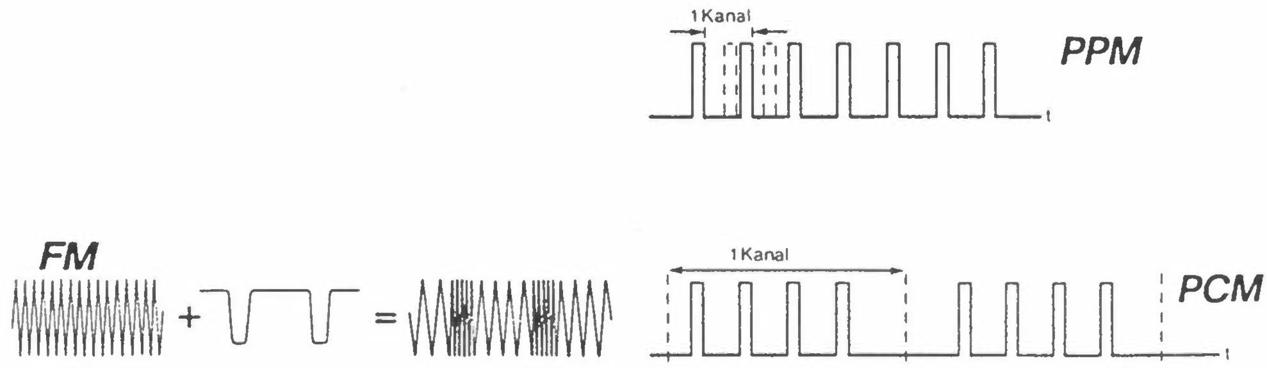
Figur 6: Enkelt fjernstyrt fly, tilpasset for prøvetaking og fotografering.



Figur 7: Figuren viser "MATS-C DOLPIN", et fjernstyrt fly bygget med "COMPOSITE-teknikk".

3.1 STYRING OG KONTROLL

Nye radiofjernstyringssystem basert på "Puls Code Modulation - Double Superhead" (PCM-DS), se fig. 8, er meget pålitelige og godt egnet til fjernstyring av fly. Den store fordelen med PCM-DS fremfor FM er at støy ikke vil ha innvirkning på forholdet mellom flyet og piloten.



Figur 8: Figuren viser forskjellene på Frekvens Modulation (FM) og Puls Code Modulation - Double Superhead (PCM-DC).

Rekkevidden er tilstrekkelig til å operere trygt innen det visuelle felt (ca 1 km).

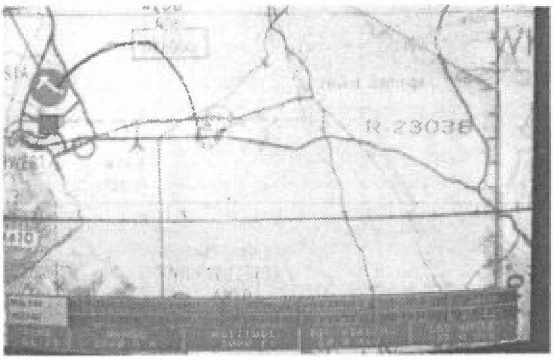
Utstyret kan suppleres med små autopilotsystemer for stabilisering av en eller flere av flyets akser, og et sikkerhetssystem kan innebygges. Dette systemet overvåker vitale funksjoner som: strømforsyningen, de mottatte signalers styrke, logikk osv. Dersom en eller flere vitale funksjoner svikter helt eller delvis, vil "fail safe" systemet gripe inn og f.eks. slå av motoren, nøytralisere alle ror og eventuelt løse ut en fallskjerm som bringer flyet trygt ned til bakken. Dette betyr at faren for havari reduseres til et akseptabelt nivå.

For flyging i ytterkant av og noe ut over det visuelle felt, kreves mer utstyr. Kombinasjonen av PCM-DS radiofjernstyring, små autopiloter og et lite TV-kamera er den mest brukte løsningen. Dette fremgår som vist av Smith, R.P. (1989).

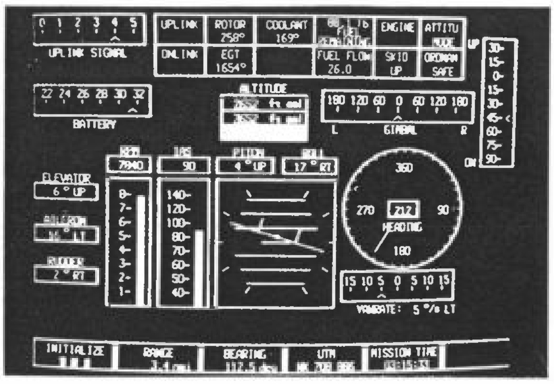
Flyet blir startet på vanlig måte, men selve flygingen stabiliseres i horisontalt og vertikalt (i roll- og pitchplanet) ved hjelp av en autopilot. Operatøren følger med på en TV/dataskjerm (som å sitte i Cockpit), se fig. 9, og styrer flyet i ønskede posisjoner for å foreta målinger. Etter endt oppdrag, styres flyet tilbake til start/ landingsområdet, hvor landing foregår visuelt.

Figur 9: Bildet viser en pilot og en hjelpemann. Piloten styrer flyet ved hjelp av et TV-bilde, hjelpemannen retter antennen til enhver tid mot flyet.

For flyging vesentlig ut over det visuelle felt, anvendes fullt programmerbare autopiloter. Flyet følges med radar og/eller en TV/datalink fra en kontrollsentral. Denne typen av fjernstyringsutstyr er i ferd med å bli tilpasset også sivile formål, se fig. 10.



Piloten kan ved hjelp av denne skjermen følge dronens posisjon i henhold til kartet.



Denne skjermen viser alle viktige flydata (tilsvarer instrumentering i cockpit).

Piloten (foran) ved utstyr som vist ovenfor. Operatøren (bak) har ansvar for måle- og prøvetakerutstyret i flyet.

Figur 10: Eksempel på kontrollsentral for fullt programmerbar autopilot.

3.2 AUTOPILOT

Stabilisering av en eller flere av flyets akser, kan være nyttig og til dels nøvendig ved flygninger i ytterkant av det visuelle felt.

Det vanligste er å bruke små autopiloter som stabiliserer flyet i roll-planet (balanseror) og pitch-planet (høyderor). På denne måten økes sikkerheten. Operatørens oppgave vil da kunne konsentreres om å navigere/styre flyet i ønskede posisjoner.

Det er hovedsakelig to prinsipp som anvendes:

1 Gyro-stabilisering av balanserorene.
Dette holder vingene horisontale, samtidig holder en trykkbasert autopilot flyet i ønsket høyde, som vist av Uwins, S.F. (1990).

2 Stabilisering av balanse- og høyderor.
Her brukes små sensorer i vingetippene, som måler atmosfærens elektriske felt og lokale variasjoner av dette. Sensorene kobles i en loop til balanseror- og høyderorservoer og flyet stabiliseres automatisk horisontalt og i ønsket høyde, som vist av Nuclear Products Corporation (1984).

3.3 NAVIGASJON

Det å kunne dokumentere flyets posisjon er som regel helt avgjørende for verdier av målingene.

Posisjonsangivelse kan gjøres på flere måter:

Visuelt

1 Ved å anvende kjente og definerte punkt i terrenget som referanser, kan en ved hjelp av tidtaking beregne posisjonen når en kjenner flyhastigheten.

2 Ved å anvende NILUs LASER-avstandsmålerkikkert utstyrt med et logger-system som logger avstand, azimut og elevasjon, vil en med god nøyaktighet kunne fastslå flyets posisjon.

Ut over det visuelle felt

3 I slike tilfeller kreves det mer avansert og kostbart utstyr. Dette gjøres som oftest ved å montere en radar-

reflektor (Transponder) i flyet og ved bruke en målfølgeradar som til enhver tid logger flyets posisjon.

Fremtidige navigasjonsmuligheter

Utbygging av satellittnavigasjon, Global Positionering System (G.P.S.) går raskt. Produsenter og forhandlere antyder at systemene vil være tilfredsstillende utbygget innen 1992. G.P.S. navigasjonsutstyr blir også miniatyrisert for å kunne dekke mange ønsker og behov i markedet. Det vil om få år bety at navigasjonsnøyaktigheten vil kunne komme ned på centimeter-nivå.

4 MÅLE- OG PRØVETAKERUTSTYR

Måle- og prøvetakerutstyr spesielt beregnet til bruk i fjernstyrte fly er utviklet og er blitt kommersielt tilgjengelig.

National Power har i samarbeid med Skyleader Limited i Storbritannia utviklet måleutstyr for måling av temperatur, fuktighet, barometertrykk og ozon. Måleverdiene sendes via en 400 MHz radiolink fra flyet til bakken "on-line", som vist av White, D.J. (1980), se for øvrig Vedlegg 2.

NILU besitter også egen kompetanse på måle- og prøvetakerutstyr: SF_6, partikkelprøvetaking og absorpsjonsteknikk, som vist av Anda, O. (1989) og Schmidbauer, N. og Oehme, M. (1987).

4.1 LUFTTRYKK

Måleren som anvendes av National Power er en National Semiconductor LX 1601A som er en integrert silicon diaphragm trykkføler, med måleområde fra 688 til 1378 mb, og følsomheten er på ±3 mb. Enheten veier 5 g og har et strømforbruk på 12V, 10 mA.

måleområde fra 688 til 1378 mb, og følsomheten er på ±3 mb. Enheten veier 5 g og har et strømforbruk på 12V, 10 mA.

4.2 TEMPERATUR

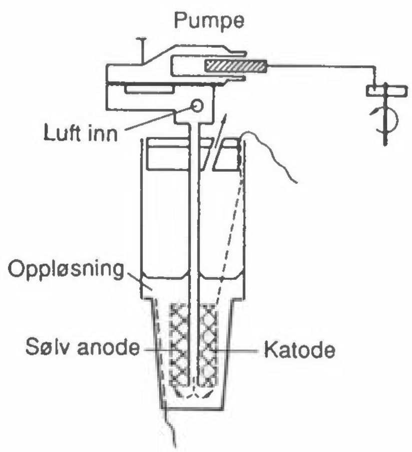
Føleren som anvendes er en Yellow Springs Industry's YSI 4403 Termistor. Den har en lineær karakteristikk mellom -10° C og +30° C. Følsomheten er ±0,2° C med en tidskonstant på 2 sekunder.

4.3 FUKTIGHET

Her brukes en våt og en tørr termistorteknikk. Nøyaktigheten er den samme som på den ordinære temperaturtermistoren. Den relative fuktigheten regnes ut i et dataprogram i maskinen på bakken. Nøyaktigheten av målingene er variabel, normalt ±5%.

4.4 OZON

Sonden som anvendes er en Mast-sonde type 730. Denne er modifisert spesielt til bruk i modellfly. Ozonsondens reaksjonstid er noe avhengig av temperaturen. Under ideelle forhold er deteksjonsgrensen 1 ppb med en eksponeringstid på 15 sek.



Figur 11: Figuren viser NPs ozonmåler som også kan brukes til måling av SO_2 og NO_x.

4.5 SF_6

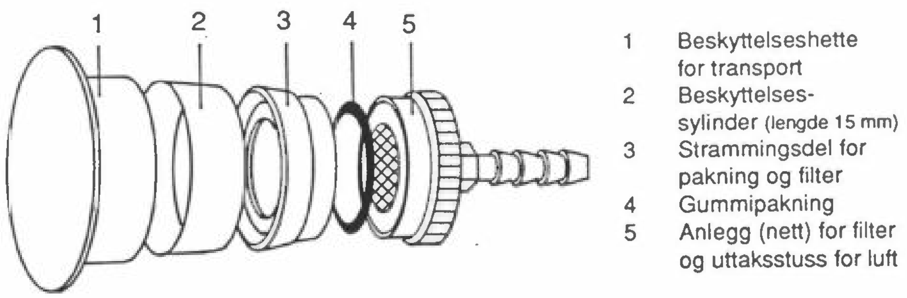
Prøvetaking kan utføres ved å montere en SF_6 prøvetaker spesielt utviklet for bruk i et fjernstyrt fly. En slik prøvetaker kan ta 2 serier à 16 øyeblikksprøver ved måling av vertikalspredning i selve plumen eller traverser av plumen. Prototypen er delvis utviklet på NILU av Reidar Heggen.

4.6 AEROSOLER, STØV OG PARTIKLER

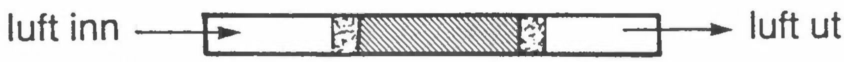
Slike målinger kan utføres ved å anvende filterholdere fra Nuclepore, modifiserte NIOSH filterholdere eller NILUs egne.

4.7 GASSER

Dette utføres ved bruk av eksempelvis absorpsjonsrørteknikk for etteranalyse i gasskromatograf.



Figur 12: Filterholder for prøvetaking av partikler i luft.



Figur 13: Prinsippskisse av et Tenax-rør for måling av gasser.

4.8 FOTO/FILM

Fotografering og filming av utslippskilder og måleobjekt kan, som vist av Ellis, R.M. og Fuller, A.R. (1979), utføres ved å montere et motordrevet stillbilde- eller videokamera inn i flyet.

5 FORMALITETER

Før flyging kan igangsettes er det visse formaliteter man må ta hensyn til.

5.1 FLYET

Det er utarbeidet internasjonale regler som definerer og setter grenser for hva som dekkes av begrepet modellfly.

- Flyet skal være ubemannet
- Flyet skal maksimalt veie 20 kg
- Motorens sylindervolum kan maksimalt være 100 ccm

Så lenge en holder seg innenfor disse grensene er det ikke uoverkommelige formaliteter i forbindelse med slike flyginger.

5.2 RETNINGSLINJER FRA LUFTFARTSVERKET

Så lenge flyene er ubemannet, og ellers ikke kommer i konflikt med annen luftfart, har Luftfartsverket ingen innvendinger mot flygingene, dvs flyging i kontrollert luftrom må klareres med den lokale flykontroll (evt. NOTAM).

5.3 FREKVENSER

Til fjernstyring av fly har Televerket øremerket spesielle frekvenser (35 MHz eller 40 MHz-området). Dersom det er ønske om å anvende andre eller flere frekvenser, f eks VHF, UHF eller TV-datalink, kreves spesielle konsesjoner, også fra Televerket.

Det må kun anvendes godkjent utstyr og lovlige frekvenser.

5.4 FORSIKRING

Flygingene må være forsikret mot skade på tredjeperson-ansvars-forsikring. NILUs forsikring dekker dette så fremt flygeren har tilfredsstillende opplæring og jevnlig vedlikeholdstrening.

5.5 "MELDEPLIKT"

Flygingene bør for å unngå unødige problemer klareres med lokale grunneiere, det lokale politi og eventuelt med forsvaret.

6 KONKLUSJONER/ANBEFALINGER

Med bakgrunn i litteraturstudier og innhentede opplysninger fra ulike brukeres erfaringer kan det trekkes følgende konklusjoner:

Det er fullt mulig å anvende droner til målinger og prøvetaking i forbindelse med måling av fysiske og kjemiske parametre i luft.

- Bruk av droner vil gi NILU mulighet til å måle i områder og i et luftsjikt der vi i dag ikke måler.

- Bruk av droner vil være den mest effektive og økonomiske metode for dette.

Anbefalinger

NILU er i besittelse av kompetanse på de fagfelt som vil være nødvendig for å sette sammen en prosjektgruppe som i løpet av relativt kort tid kan ta i bruk droner til målinger.

På kort sikt (1-2 år) vil det være realistisk å begrense seg til flyging/målinger innen det visuelle felt. En kan tenke seg følgende mulige programmer:

1. Måling av vertikal/arealprofiler av måleparametre etter behov
   1.1 Verifisering av ozon- og andre bakkestasjoner
   1.2 Måling av ozon i forbindelse med skogskader

2. Prøvetaking av industriutslipp, søppelforbrenningsanlegg, oljeplattformer og fra trafikk
   2.1 Måling av gassutslipp ved bruk av absorpsjonsrørteknikk
   2.2 Måling av aerosoler, støv og partikler ved bruk av filterholdere

3. Prøvetaking av SF_6 for måling av vertikalspredning

4. Luftfotografering av måle/utslippsobjekt
   4.1 Stillbilder
   4.2 Film
   4.3 IR

<u>På lengre sikt (2-6 år)</u>

Ved positive erfaringer fra et pilotprosjekt som antydet ovenfor, bør droneteknikken videreutvikles, eventuelt i samarbeid med andre institutt.

7 REFERANSER

Ames, D.L. (1979) Electrochemical cells for measuring ozone in air. Leatherhead Central Electricity Research Laboratories, (RD7L/N2/79).

Ames, D.L. (1981) Atmospheric ozone profiles at an industrial site near Gent, Belgium, during June 1981. Leatherhead Central Electricity Research Laboratories (RD/L/2172N81).

Anda, O. (1989) Mineralfiber som luftforurensning. Del 2 - Prøvetaking og identifisering (lysmikroskop). Lillestrøm (NILU TR 5/89).

Ellis, R.M. and Varey, R.H. (1978) Small weather and atmospheric sampling platforms for air pollution measurements. Leatherhead Central Electricity Research Laboratories (RD/L/N31/78).

Ellis, R.M., Fuller, A.R. and Whitby, S.R. (1979) Aerial photography of Fawley shoreline using WASP III. Leatherhead Central Electricity Research Laboratories (RD/L/N174/78.

Hill, M.L. (1975) Method and apparatus for attitude detection and stabilization of airborne vehicles using the electrostatic field in the earth's atmosphere. Laurel, Maryland The Johns Hopkins University, Applied Physics Laboratory, (U.S. patent No. 3.868.074).

Hill, M.L. and Whyte, T.R. (1975) Investigations related to use of atmospheric electric fields for model aircraft and Remotely Piloted Vehicles stabilization. Laurel, Maryland. The Johns Hopkins University, Applied Physics Laboratory (APL/JHU TG 1280).

Hill, M.L. and Whyte, T.R. (1978) Remote detection of chimney plumes by means of atmospheric electric fields. I: Conference Proceedings of joint conference on sensing of environmental pollutants, New Orleans Nov. 1977.

Hill, M.L. (1984) Electrical disturbances near thunderstorms observed by means of small remotely piloted aircraft stabilized with respect to the local field vector. I: VII internat. conf. on atmospheric electricity, Albany 1984. pp 272-278.

Horcicka, V. (1980) SAM - Flugmodelle im Dienste der Wissenschaft und Forschung., VOL III. Modellflug, 1980, 491-492.

McDonald, C., Izquierdo, M., Ballard, H.N., Smith, J. and Quintana, F. (1984) The Maneverable Atmospheric Probe. APL MAP/UV 8001. University of Texas, El Paso, Applied Physics Laboratory. (Report No. FRI-84-AR-140.ARO-17511.I-GS).

Nuclear Products Corporation (1984) Static Masters (TM). Autopilot for unmanned aircraft. El Monte, California.

Schmidbauer, N. og Oehme, M. (1987) Modifications of a Commercial Thermodesorption Unit to Obtain More Efficient Cryotrapping and Compatibility With a Mass Selective Detector (HP5970). J. High Res. Chrom. & Chrom. Comm., 10, 398-400.

Smith, R.P. (1989) Unmanned Aerial Vehicles. Model aviation, 15, 91-97.

Totten, J.A. (1981) A solid state tropospheric radiosonde. Leatherhead Central Electricity Research Laboratories (RD/L/2169 N81).

Uwins, S.E. (1990) Skyleader autopilot systems for remotely piloted aircrafts. Croydon Skyleader Limited.

White, D.J. (1980) A microprocessor-based system for environmental data collection in a model aeroplane. Leatherhead Central Electricity Research Laboratories (RD/L/N41/80).

Zafir, H., Steinitz, G., Yaffe, U., Pernick, A., Altman, A., Grushka, A. (1990) Unmanned Airborne System for real-time Emergency Nuclear Monitoring. Presented at IAEA: Utilization of airborne monitoring systems during and following nuclear accident situations, Vienna.

VEDLEGG 1

A microprocessor-based airborne data collector

SUMMARY

This Note describes a microprocessor-based airborne data collection and transmission system used for environmental measurements and mounted in a model aeroplane. The system measures pressure, temperature, humidity and ozone concentration and transmits these values over a 403 MHz radio link from the aircraft to the ground in a suitable form for processing and plotting by a ground-based computer system.

The package has been successfully used in measurement exercises at Didcot Power Station and at Turbigo in Italy during a joint EEC measurement campaign.

1. INTRODUCTION

For several years C.E.R.L. has been involved in the investigation and understanding of the process of dispersal of plumes from the chimneys of the C.E.G.B. power stations. Several factors influence the physical dispersion and chemical changes within the plume, not the least of which are the prevailing meteorological conditions.

After investigating the viability of kites, free and tethered balloons and model helicopters as mobile atmospheric measurement platforms, it was decided to use model radio-controlled aeroplanes as these provide the required flexibility of operation with a suitable payload (Ellis and Varey, 1978; Chester, 1979).

The first measurement technique used was to mount a commercially available meteorological sonde (made by Grau Inc.) in the plane, and this performed moderately well although only designed to transmit pressure, temperature and humidity while attached to a slowly rising balloon. However it could provide no other facilities and suffered badly from vibration problems within the plane, so the requirement arose to replace the Grau Sonde with a more suitable sensing and transmission system which could function in the plane and provide an easy interface with a ground-based computer used for on-line plotting of profiles.

2. FUNCTIONAL REQUIREMENTS

The functional requirements for the system were to measure barometric pressure (in order to gauge the altitude of the plane), temperature and humidity, and to interface with an ozone sensor and transmit the values of all of these variables to the ground. In addition the system should be expandable to other parameters and functions, such as local control of the aircraft, and, of course, the system should be light, small and battery operated.

The requirements for expandability, flexibility of function and small size suggested strongly the use of a microprocessor, so a basic design was drawn up using a Motorola 6802 microprocessor.

3. SYSTEM DESCRIPTION

The basis of the system is a single Eurocard sized board which takes eight voltage input channels, digitizes them in sequence and produces a modulating signal for a small 403 MHz radio transmitter. The transmitted data are comprised of a stream of alphanumeric characters which specify, for each channel, a channel identifying character plus a three digit number giving the channel voltage in millivolts, these characters being ASCll coded to give a serial bit stream which in turn produces a two tone frequency shift keyed (FSK) modulation signal. This coding technique used to transmit characters is essentially the same as that used in modems to enable computer communications through a variety of media.

The microcomputer is used to control the scanning of the input channels, convert the digitized values to the appropriate format, produce the bit serial data stream and also to perform the extra functions required e.g. height control of the plane.

The rest of the system consists of the measurement transducers for pressure, temperature, humidity and ozone, signal conditioning for these parameters and the 403 MHz radio transmitter.

Of the eight input channels available four are used for the measurements just mentioned, a fifth monitors the aircraft's radio control battery, and the other three are available for immediate use as extra channels.

Fig. 1 shows a block diagram of the system.

4. MEASUREMENT TECHNIQUES

4.1 Atmospheric Pressure

The pressure transducer used is a National Semiconductor's LX 1601A, which is an integrated, silicon diaphragm pressure sensor with built-in signal amplification, having a range of 10 to 20 p.s.i.a. (688 to 1378 m Ba) and a quoted resolution of 0.05 p.s.i.a. (3 mB) which includes hysteresis and repeatability errors. Over the range of altitudes that the plane operates this represents a height error of 25 m. The transducer weighs 5 gm, requires 12 V at 10 mA and produces a signal from 1 V to 11 V for a full scale deflection. The signal is divided by a resistive potential divider to give a full scale of 1 V, to feed to the main microcomputer board. The air pressure is fed to the transducer from a static tube mounted on the front edge of the aircraft wing, to minimize the effects of varying air speed on the barometric reading.

4.2 Temperature

This parameter is measured using thermistors, the actual sensor used being the Yellow Spring Industry's YSI 44203 which is mounted under the aircraft wing in a radiation shield. This sensor comprises a small pair of thermistors bonded together which, when combined with a pair of precision resistors in a bridge network and supplied with a fixed voltage, produce a voltage output with a linear relationship to temperature. This signal is conditioned for range and offset using operational amplifiers and the input to the microcomputer board is 0 to 1 V for a temperature range of -10°C to +30°C. Resolution is quoted as infinite but is limited in practice by the 1 mV resolution of the analogue to digital conversion used by the microcomputer, equivalent to 0.04°C. A more realistic parameter however is the repeatability, which is 0.2°C. The time constant of the thermistor pair is observed to be about two seconds in moving air.

4.3 Humidity

Humidity is measured using the wet and dry bulbs technique; in this case wet and dry thermistors are used. The dry temperature is provided by the normal temperature measurement and the wet bulb temperature is measured using a similar thermistor sensor with a wet wick surrounding it. This wick is kept moist by a small cotton wool reservoir in a plastic bag and the whole is mounted beneath the aircraft wing, again with a radiation shield for the thermistor. Aspiration of the wet thermistor is by normal airflow past the wing and the reservoir contains sufficient water for over thirty minutes of flight. Signal conditioning and performance factors are the same as for ordinary temperature and the ground station computer performs the necessary computations to extract the humidity figure from the wet and dry temperatures.

4.4 Ozone

A commercial ozone sonde, type 730-72 made by Mast, measures ozone concentration and this, its modification and associated electronics are described by Ames (1979).

The output from the sonde is scaled 0 to 1 V for 0 to 170 p.p.b. of ozone.

5. DATA CODING AND TRANSMISSION

Fig. 2 shows the block diagram of the microcomputer board. The eight channels of signals to be measured, each being in the range 0 to 1 V, are connected to the analogue multiplexer. The microprocessor, through the digital interface circuit, instructs the multiplexer to switch one of these signals to the analogue to digital converter, which performs continuous conversions of its input voltage. After a short settling time the microprocessor reads the converted value of the signal from the analogue to digital converter (ADC) in the form of three binary coded decimal (BCD) digits which it stores internally and, after adding another character for identification, sends the data as an ASCll coded string of alphanumeric characters (byte serial, bit parallel) to the bit serial interface circuit. This produces a stream of serial bits (at 300 b.p.s.) which goes in turn to the modem chip where each bit produces one of a pair of frequencies (2050 Hz for an '0', 2250 Hz for a '1'). This frequency shift keyed signal is then used to amplitude modulate the carrier of the 403 MHz radio transmitter. The transmitter is manufactured by Plessey for meteorological radio sondes and has a nominal power of 120 mW.

6. DATA RECEPTION AND DECODING

At the ground receiving station the radio signals are picked up on a standard radio receiver, demodulated, and the two-tone FSK signal is filtered and passed to a modem circuit similar to that in the plane. This reconstitutes the logic level bit stream which is converted to a set of alphanumeric characters in a Motorola microcomputer where, after data validation, it is passed to a DEC PDP 11/03 computer for processing and on-line plotting of data.

7. EXPERIENCE WITH THE SYSTEM

The system has been used several times for measurements in the area of Didcot Power Station and also extensively during a joint EEC measurement campaign in the area around Turbigo Power Station, in Northern Italy in September 1979. The full results will be published elsewhere in due course.

There were, of course, the usual teething troubles with the system, the radio transmission providing the most vexatious problems. Vibration in the plane had produced extra modulation of the original transmitter swamping the required modulation signal, simply by mechanical variation of circuit components' geometries and hence capacitances. This was overcome by using a more stable, crystal controlled, transmitter packing it in plastic foam and mounting the aerial under the wing away from the main sources of vibration, the engine and propellor airflow. The transmitter and receiver aerials were designed to give minimum directionality as the plane's attitude and position are continually varying.

All of the circuit boards have to be protected against vibration and for the microcomputer board this meant packing it and the signal conditioning board in foam in a box inside the fuselage. This worked perfectly well in England, but in Italy, with higher ambient temperatures, the circuits suffered from overheating. One integrated circuit suffered permanent damage and had to be replaced and the microprocessor itself malfunctioned several times due to overheating. Temperatures of 80°C were recorded using temperature sensitive labels on the main microcomputer circuits.

Aside from these problems the system has worked well, providing automatic on-line plots of vertical temperature and ozone profiles. The plots show a good repeatability, this being most noticeable in the comparison of temperature profiles during the up and down sections of measuring flights. Fig. 3 shows a typical plot produced during the Italian exercise. The three traces are ozone, temperature and battery volts (ascending and descending); humidity was not being plotted. It can be seen that 'up' and 'down' temperatures are closely superposed; ozone readings are different because conditions changed and because of time lag in the sensor.

8. FUTURE WORK

This work falls into two areas, namely improving the characteristics of the system and increasing its functions.

Improvements can be made in the weight, power dissipation and battery requirements by using lower power, more highly integrated versions of the computer circuits, e.g. the Intersil CMO5 87C48 microcomputer could replace four of the main circuits and cut power dissipation by at least one order of magnitude. This would eliminate the overheating problems and use lighter batteries which in turn would enable smaller, more mobile planes to be used.

Extra functions to be incorporated include control of the plane to keep it in even level flight. At present visual contact, and hence pilot control, is difficult above 1 km range even in good visibility. This range is considerably reduced in poor visibility and as some measurements may be required to be made within cloud, e.g. pH of rainwater etc., some provision for blind flying must be made. This requires local control of the plane by the microcomputer. At present the microcomputer can control the height of the plane using the pressure reading and activating the elevator control when necessary. This is far from being complete, however, and needs more work to define time constants, control loop gains etc., but it will help blind flying and also reduce pilot fatigue during normal conditions.

9. CONCLUSIONS

A basic environmental measurement data collection and transmission system has been designed and built to fly in a model aircraft and give accurate data on vertical profiles of temperature, humidity and ozone. It has the capability of expansion to further measurements and functions and will enable a wide variety of previously infeasible environmental measurements to be made.

10. ACKNOWLEDGEMENTS

I should like to acknowledge the advice of the Meteorological Office at Bracknell on sensing devices and the assistance of Mr J.A. Totten for design and construction of the signal processing circuitry.

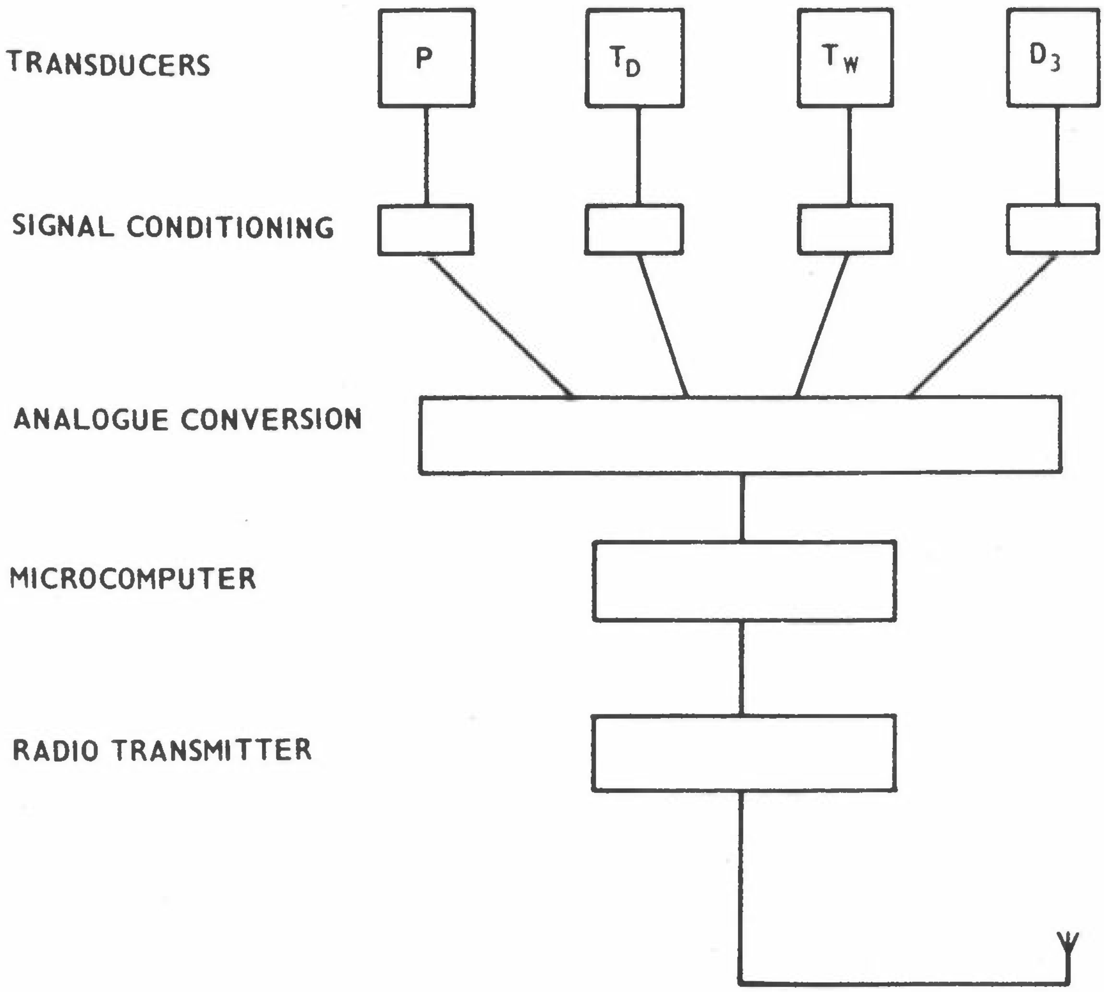


FIG. 1 SYSTEM BLOCK DIAGRAM

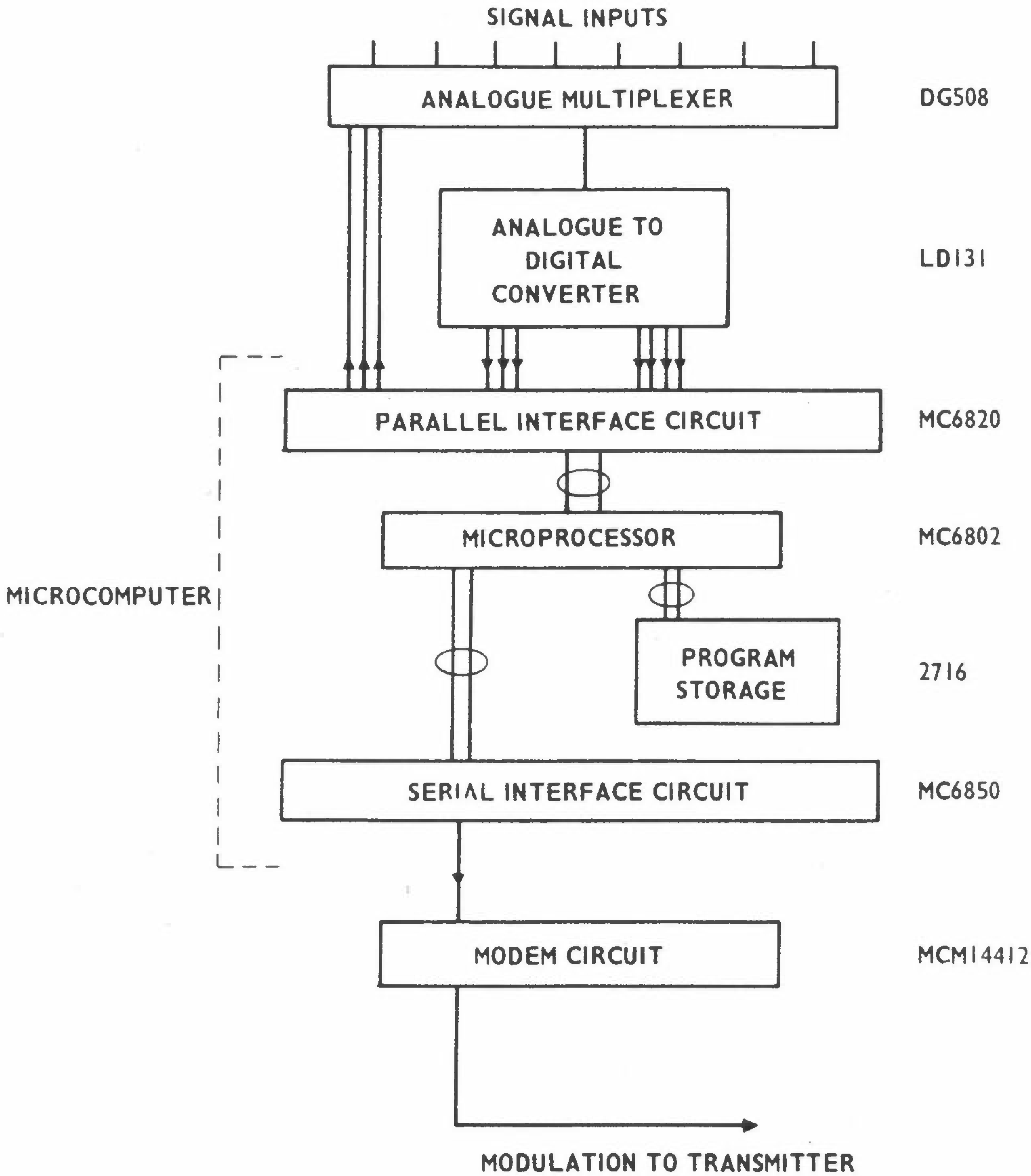


FIG. 2 THE MICROCOMPUTER BOARD

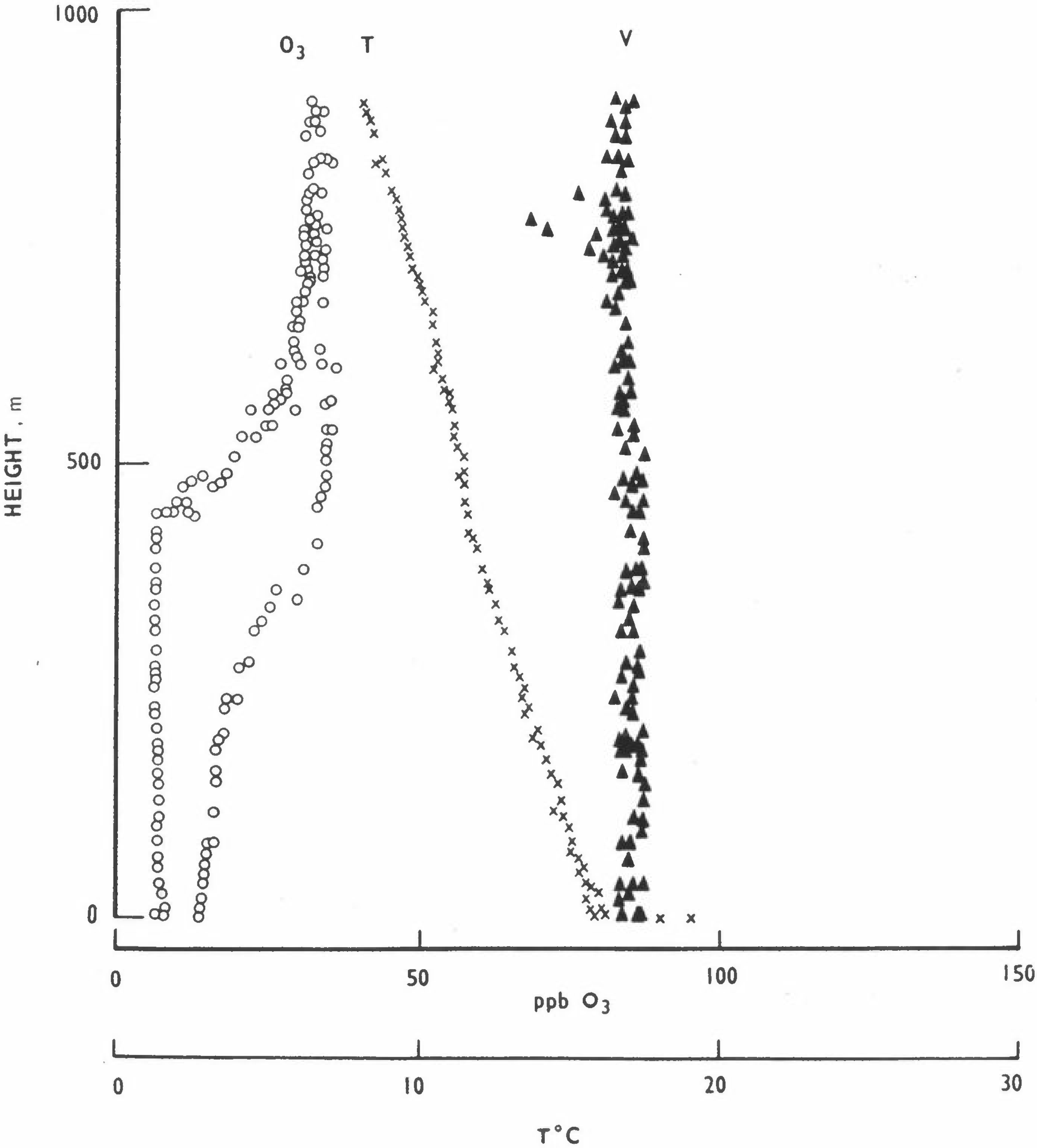


FIG. 3 A TYPICAL PLOT

VEDLEGG 2

Atmospheric ozone profiles, Gent, Belgium

RD/L/2172N81

ATMOSPHERIC OZONE PROFILES AT AN INDUSTRIAL SITE NEAR GENT, BELGIUM, DURING JUNE 1981

by

D.L. Ames

SUMMARY

This Note presents the vertical ozone and temperature profiles obtained at a site a few miles north of Gent, Belgium, as part of the 5th CEC Campaign on the Remote Sensing of Atmospheric Pollution. Also presented are ground level ozone and sunshine levels recorded at the same site during the eight days that measurements were taken. The profiles are discussed briefly in terms of the prevailing meteorological conditions. For much of the time only low ozone levels were observed, due doubtless to the many nearfield emission sources in the area. But on several days when there was a favourable light easterly wind, somewhat higher ozone levels (50-60 ppb) were recorded. Some early mid-morning ozone profiles were recorded under these conditions, which confirm that photochemically generated ozone can persist above the nocturnal inversion layer almost unchanged. Beneath the inversion ozone depletion occurs, chiefly, it appears, by deposition to the ground. Measurement of similar day- and night-time ozone profiles at a rural site would be a worthwhile method of studying ozone build-up and depletion mechanisms.

Job No. VF 421

Approved: A. B. Hart

A.B. Hart

Head: Chemistry Division

Date: 19-11-81

1. INTRODUCTION

A team from CERL participated in the 5th CEC Campaign on Remote Sensing of Atmospheric Pollution held in Belgium during June 1981. The chief object of the campaign was to determine SO_2 burdens and derive a sulphur budget for the Gent region: but somewhat as a sideline vertical ozone profiles were determined at a fixed site. This was carried out using radio-controlled model aircraft, similar to that described by Ellis and Varey (1978). Temperature profiles were also recorded, which complemented the meteorological information obtained from other teams. The same site was used for the launching of wind-tracking pilot balloons, and ground-level ozone and solar radiation measurements were also taken there.

This site was in open ground adjacent to the Texaco Research Centre, approximately 10 km NNW of the centre of Gent. The area is heavily industrialized (Fig. 1), but the industrialization is confined to a fairly narrow strip on either side of the ship canal connecting the port of Gent with the estuary of the Schelde. Immediately to the north of the site the local power company EBES operates a medium-sized power station: there is an oil refinery to the south-east, and a titanium dioxide plant and sulphide ore smelter to the south-west. Ground level pollutant concentrations at the site can be very high, particularly when the wind is blowing from the latter direction. It can be seen that only with easterly or due westerly winds is there much chance of avoiding heavy interference with the ozone measurements by near-field plumes.

The aircraft-mounted ozone sensor was a modified Brewer-Mast ozone sonde, and has been described previously (Ames, 1979). Since this description was published, ozone profiles have been obtained on a number of occasions, including the 4th CEC Campaign at Turbigo, Italy in 1979. Experience showed that the multichannel microprocessor-controlled data transmission system (White, 1980), with its associated batteries, was rather unreliable and too heavy, and has now been discarded in favour of a much simpler system based on a modified Grau meteorological sonde (Totten, 1981). This permits a smaller and more easily controlled airplane to be used for the profiles, but has the disadvantage that only two channels of data can be handled (barometric height and either temperature or ozone concentration). In obtaining a profile the usual practice is to operate in the temperature mode on the ascent stage of the flight, and to record ozone concentration on the way down, the changeover being effected by a switch linked to the aircraft's radio control gear. As before, the data points are received by a ground station incorporating an on-line computer, and the profile is plotted out continuously during the flight.*

The electronics associated with the ozone sensor have been modified to operate with the Grau sonde (by incorporation of a voltage-frequency converter), and various minor improvements have been made to the regulation of the bias potential on the cell etc. Since SO_2 concentrations in the area were likely to be high, a chromic acid filter was used with the sensor to prevent negative interference to the ozone readings. A similar ozone sensor was used to obtain ground level readings.

---

*The ozone cell is pressure sensitive, but the readings have not been corrected for this. For the curves presented here, the error is always less than 2 ppb.

For calibration purposes a Mast Oxidant Monitor, coupled to an ozone generator, was used; this having previously been checked against a Columbia Scientific Instruments MEC 1000 standard ozone source. During the daytime, ground level solar radiation measurements were made using a Kipp and Zonen Solarimeter (type CM 5).

2. RESULTS

Fig. 2, 3 and 4 show the records of ground level ozone and solar radiation (the latter readings being averaged over 10 minute periods) obtained at the Texaco site on Monday-Wednesday 15-17 June 1981. No vertical ozone profiles were obtained on these days as the weather was not suitable, being rather windy. On Monday the winds began from a south-westerly direction, but veered to due west by early afternoon; by then the sky had begun to cloud. Ground level ozone concentrations were low throughout the day which is expected since for much of the time the site lay in the path of plumes from the chemical plants on the other side of the canal. Tuesday began bright and clear with relatively 'clean' NW winds, but again clouded during the afternoon. In the absence of near-field plumes, ozone levels were somewhat higher, but no higher than the expected background levels for clean air. On Wednesday there was a fairly strong westerly wind, with frequent rain and ozone levels constant at about 20 ppb.

The ground level sunshine and ozone measurements for Thursday 18 June are shown in Fig. 5. There was a moderate northerly wind, and again the ozone levels were constant at or slightly above 20 ppb. A total of 5 model aircraft profiles were taken during the day (Fig. 6 to 10). Flight 3 ended prematurely owing to engine trouble on the aircraft and on flight 5 only temperature was recorded since the ozone sensor failed during the flight. As would be expected in such windy conditions the ozone profiles showed a more or less uniform distribution, with very little ground-level shear. The temperature profiles, too, showed a uniform gradient with little definite structure, and a lapse rate close to the theoretical dry value of 9.8°C km^{-1}. The sun came out while flight 5 was in progress, which accounts for the descending temperature profile being displaced from the ascending one, especially near the ground.

On Friday 19 June there was a light SW wind, which brought the plume from the chemical works over the measurement site. The sunshine and ozone levels are given in Fig. 11, and the profile obtained shortly before mid-day in Fig. 12. As expected the ground level ozone concentration was very low for most of the day, and low values were also observed in the profile. The structure observed in the profile reflects the varying trajectories of the near-field plumes: little information can be derived from this however in view of the complexity of the situation and the absence of detailed information on the plume trajectores at the measurement site.

Fig. 13 gives the ground level ozone and solar radiation readings for Monday 22 June. The winds were quite light and came mostly from the north. So the measurement site is likely to be affected by plumes from the Rodenhuize Power Station immediately to the north of the site, as well as the steelworks a few kilometres away. This probably explains the occasional dips in the otherwise fairly smooth ozone curve. Three flights were carried out in the afternoon (Fig. 14 to 16). The temperature plot in flight 7 shows a slight reduction in gradient between 700 and 800 metres, implying that vertical movement of air is likely to be reduced at that level. There is correspondingly a change in the ozone level there, but otherwise the ozone profiles are all fairly uniform, except for the depletion of ozone at about 300 metres in flight 7. The relative sharpness of the depletion, and the fact that it is not reproduced in other flights, suggests that the airplane had passed into a well-defined near-field plume, presumably from the power station. The average ozone concentration in the flights was about 36 ppb, but in flight 8 there was a noticeably higher concentration on the downward flight, particularly at the lower levels. This could have been simply a consequence of the fluctuating penumbra of a medium field plume; or photochemical ozone generation could have occurred during the progress of the flight. However, the ground level readings do not change, and there is not a very clear correlation with the sunlight records.

Tuesday 23 June began bright and clear, with easterly winds. From this direction there were no major near or medium field emission sources, and the ground level ozone readings reached about 45 ppb by midday (Fig. 17). Five airplane flights were carried out between late morning and mid-afternoon (Fig. 18 to 22). In flight 10 the temperature gradient is slightly less than the predicted dry adiabatic gradient, so that there should be a degree of vertical stability. This is borne out by the ozone profiles, which show a definite layered structure. In the first profile (Fig. 18(b)), the ozone concentration reaches 35 ppb above 500 metres, and this concentration has perhaps been carried over from the previous day. Below that height there is considerable ozone depletion. However, on subsequent profiles this structure begins to break up, and by the next flight the lower part of the profile overtakes the upper part, with a considerable ozone bulge forming (Fig. 19(d)). (The time lapse between the bottom of profile 19(c) and the bottom of 19(d) is about 10 minutes.) This flight also corresponds with a period of rapid increase in the ground ozone values. The ground value reduces after the sky begins to cloud over (e.g. between 12.30 and 13.30), but it nevertheless has a general upward trend throughout the afternoon; some photochemical generation of excess oxidant must be occurring. The remaining vertical profiles (Fig. 20 to 22) all show a more or less uniform ozone distribution with the ozone levels gradually rising.

Ground level ozone readings were taken at several times during the night of 23/24 June (Fig. 23). During the night the winds were very light and variable in direction, and the ozone concentration decreased with a half-life of about 3 hours. The winds remained light on the morning of the 24 June, which was a warm and rather hazy day. The sunshine and ground level ozone recordings are shown in Fig. 24; the ozone level remained low until about 10.30 and then rose slowly. A total of seven airplane profiles were carried out during the morning, including some early flights soon after sunrise (Fig. 25 to 31). The first flight of the day (No. 15; Fig. 25) shows a pronounced temperature inversion below 200 metres, and the ozone plot is also considerably stratified. Above 200 metres the ozone concentration is fairly high, at about 55-60 ppb, and this must be a remnant of the photochemical ozone formation the previous day. Below that level the ozone is strongly depleted, with the concentration falling off gradually to its ground level value. Comparison with flight 16 shows an ozone bulge forming at about 200 metres, which by flight 17 has disappeared. A possible explanation is that the flight 15 profile represents the 'simple' situation, with ozone depletion depending inversely on height, and in flights 16 and 17 the profile shows the effect of having been 'eaten into' by a well-defined NO-rich near field plume. Unfortunately there was no wind data recorded immediately before these flights. The nearest pilot balloon launch was at 05.58, which showed a light ESE wind of about 2 m s^{-1} extending up to 400 metres, and winds of less than 1 m s^{-1} of variable direction above that height. It is not obvious where any nearfield plume could have come from, since the aircraft did not fly through the visible plume of the refinery.

The layered structure of the ozone plot persists until flight 20, (flight 19 must be regarded as unreliable since the ozone sensor pump battery was found to be exhausted on landing). In flight 21 the profile was much more uniform, and the air stability as determined by the temperature profile, was much less marked. The apparent loss of ozone at high altitude is difficult to explain: it may be a temporary failure in the ozone sensor, but unfortunately it was not possible to repeat that measurement.

3. DISCUSSION

The Texaco site was not very suitable for studying ozone chemistry, since there were too many nearfield sources to confuse the issue. Nevertheless a few general comments can be made.

3.1 Background Ozone Levels

During the final week of the campaign it seems that the air came mainly from a coastal direction, and was, apart from nearfield sources, fairly unpolluted. The ozone levels measured therefore would not be too different from the natural background. This background normally lies between 20 and 40 ppb, and is mostly a result of subduction from the stratosphere. Although the temperature gradient at the tropopause acts as a 'lid' and prevents large scale mixing of the atmosphere, nevertheless there is evidence that stratospheric air can be entrained into lower altitudes by the circulation processes associated with surface pressure troughs (Johnson and Viezee, 1981). A consequence of this is that background ozone levels at the surface are highest in the wake of a depression. The ozone levels measured during the first week were always less than 30 ppb, and do not indicate any exceptional processes.

3.2 Daytime Photochemistry

During the second week it seems that ozone levels in excess of the natural background were being observed. The winds came predominantly from the north and east, so the ozone probably originated from emissions of NO_x and hydrocarbons in the industrial hinterland of Europe. It is known that an ozone plume can persist for several days and travel up to 1000 km (Cox et al., 1975). Unfortunately measurements of NO_x and hydrocarbons were not available at the Texaco site, but some tentative conclusions can be drawn from the timescale of ozone production.

According to the 'classical' theory of photochemical ozone formation (see e.g. Calvert, 1976a,b) ozone generation results from the slow oxidation of hydrocarbons, with the systems NO_2/NO and HO_2/HO being catalytically conserved chain carriers. Fig. 32 gives a very much simplified scheme for the degradation of a typical hydrocarbon. As is well-known, the components of the NO_x cycle are in rapid equilibrium, and a photostationary state is assumed:

$$[O_3]\,[NO]/[NO_2] = J/k_3$$

k_3 is the rate of reaction 3 in Fig. 32. Its typical value* is 0.024 ppb^{-1} min^{-1}. J is the overall rate of the first two reactions, and it is composed of such terms as the solar irradiance below about 395 nm, the absorption coefficient of NO_2 and the quantum yield for NO_2 dissociation. But in calculating it from first principles it is also necessary to take into account the albedo (proportion of light reflected from the surface), the absorption of sunlight by stratospheric ozone and by the polluted layers themselves, and the scattering of light by molecules and particulates. J values may reach 0.55 min^{-1} under noonday Los Angeles conditions (Calvert, 1976a), giving a photostationary constant J/k_3 = 20 ppb.

A consequence of the photostationary equilibrium is that in the presence of significant NO_x, a proportion of the ozone will be 'locked up' as NO_2 under dark conditions and released again when the sunshine level increases, so that there would be a fairly rapid correlation (e.g. within a minute or so) between the fluctuating sunlight intensity and ozone levels. In these results, such a rapid correlation was in general not observed; for example, on the 23 June at 12.15 the sunlight level dropped by 30%, but the ground level ozone reading did not change until ½ hour later. (A solarimeter sensitive only to the near UV portion of the spectrum might show a clearer correlation however.) This suggests that the air passing over the measurement site was not particularly NO_x-rich, i.e. it was a 'rural' atmosphere rather than an 'urban' one. The distinction arises because there are photochemical 'sinks' for NO_x (producing ultimately nitric acid and inorganic nitrates) and its half-life is a few hours: so rural photochemistry tends to be NO_x-starved, whereas most NO_x sources are primary emissions located in urban areas.

The rate determining step of the hydrocarbon oxidation process is the initial attack by the OH radical (Fig. 32). This leads by a series of rapid reactions to species such as RO_2 and HO_2 which can oxidize NO to NO_2 and hence lead to production of oxidant. Hydrocarbons vary in their reactivitiy to OH. Some natural high molecular weight hydrocarbons, terpenes and the like, react particularly fast, with half-lives under typical conditions as short as $\frac{1}{4}$ hour. Methane itself on the other hand is particularly unreactive, and is often ignored altogether in modelling studies. (But this is partly offset by its much higher ambient concentration, and it has been shown (Calvert, 1976b; Chameides and Stedman, 1976) that it can make a significant contribution to the overall photochemical ozone formation rate.) So the rate of production of ozone should be determined by the concentration and nature of the primary hydrocarbon pollutants.

But there is another important parameter, the concentration of OH itself. Some of the important sources and sinks for this are shown in Fig. 32. It is only quite recently that reliable direct measurements of OH concentration have been obtained for the troposphere (by the laser-induced fluorescence method), and a typical measured value near a plume is 0.04 ppt (Davis et al., 1979). This compares with values 0.02 to 0.2 ppt estimated by Calvert (1976b) in his Los Angeles smog studies. Incidentally, it has been suggested (Gillani and Wilson, 1980) that, at least in a plume, ozone concentrations can be used as a 'surrogate' for OH levels. Certainly, there must be a link between [OH] and rate of production of ozone, but the analogy cannot be pushed too far.

---

*Unless otherwise stated, all rate constants are from Graedel, Farrow and Weber, 1976, (and references therein) and are quoted at 25°C.

Ozone has relatively few sinks and can persist for long periods, unlike OH which reacts rapidly with almost everything, and whose concentration is maintained by dynamic equilibria.

Nonetheless most of the sources of OH are directly or indirectly photolytic, so OH levels will probably be a function of sunlight intensity. This would account for the observed delay between increasing sunlight intensity and increasing ozone concentration (Fig. 17). To summarize then it seems that the air being observed is hydrocarbon-rich but somewhat NO_x deficient, and that ozone levels a good deal higher would probably be observed downwind of the Gent region, after entrainment of local sources of NO_x.

3.3 Night-time Ozone Depletion

With the formation of the nocturnal inversion layer, the chemistry above the layer becomes decoupled from the ground. Modelling studies in this region are fairly easy to carry out, since it can be assumed that the air is well-mixed, and the effect of ground deposition and ground-based emission sources can be disregarded. At first sight in the dark all OH production and hydrocarbon degradation should cease; but there are some slow dark reactions which can produce OH (Anderson, 1979):

$$O_3 + \text{Olefin e.g. } C_3H_6 \rightarrow \begin{cases} CH_3CO_3^{\cdot} + H_2CO + \dot{O}H & k = 9.6 \times 10^{-6}\ \text{ppb}^{-1}\ \text{min}^{-1} \\ CHO_3^{\cdot} + CH_3CHO + \dot{O}H & k = 8 \times 10^{-6}\ \text{ppb}^{-1}\ \text{min}^{-1} \end{cases}$$

Under typical initial conditions Anderson predicts almost complete removal of NO_x and significant removal of hydrocarbons, but relatively little loss of ozone. Within the inversion layer however, any night-time NO emissions will become trapped and rapid ozone depletion should occur. There will also be a loss of ozone to the ground (deposition velocity on a dry grassy surface is about 0.5 cm s^{-1} (Garland and Penkett, 1976)).

Depletion of ozone beneath an inversion layer is fairly well established. For example Swinford (1980) has recorded markedly different ozone levels at the top and bottom of a skyscraper building in Chicago, and van Dop, Guicherit and Lanting (1977) have measured ozone profiles by monitors installed up a 200 metre meteorological mast. Tethered balloons have been used to support ozone sensors by Harrison et al. (1978), and recently Broder, Dütsch and Graber (1981) have studied the nocturnal ozone profile in a flat-bottomed valley in Switzerland. In the last three cases, ozone depletion was ascribed entirely to deposition to the ground. In our case, the half-life of the ground level ozone concentration recorded on the night of 13/24 June was 3 hours, which agrees with the value obtained by Harrison et al. (1978) over a similar dry grassy surface. However, calculation of the deposition velocity from this requires a knowledge of the depth of the well-mixed layer near the ground from which ozone depletion is occurring. Since the early morning profile (Fig. 25) shows this depth to be virtually zero, an alternative approach must be adopted (van Dop, Guicherit and Lanting, 1977). The time-dependence of the night-time vertical profile must be studied, from which the net ozone flux to the ground can be calculated, and the deposition velocity can be related to this.

Obtaining these vertical profiles throughout the night is not at the moment feasible using the model aircraft. However, the cheapness and moderate reliability of the Brewer-Mast ozone sensor makes it possible to use an array of these sensors fixed at intervals to the tethering cable of a balloon. It would not be necessary to fly the balloon at a great height (about 300 metres would be enough), but it could be left to give continuous 24 hour ozone profiles of the lowest part of the boundary layer. Such a facility would be a valuable complement to the model aircraft work.

4. CONCLUSION AND RECOMMENDATIONS

The use of model aircraft fitted with ozone sensors has again proved to be a valuable method of obtaining ozone profiles up to a height of about 1 km. At this site, though, detailed interpretation of the results is difficult due to the large number of nearby emission sources. It would be worthwhile therefore to carry out more experiments under stable atmospheric conditions at a site with no nearfield sources and where any mid-field sources can be accurately taken into account. More background information is needed, such as ground level NO_x measurements. Finally the use of tethered balloons should be considered for studying the night-time ozone depletion mechanisms. These experiments could provide a useful insight into background and plume photochemistry.

5. ACKNOWLEDGEMENTS

The assistance of Mr R.M. Ellis, Mr A.R. Fuller, Mr J.A. Totten and Mr A.J. Howe in the model aircraft work is gratefully acknowledged. Thanks are also due to Dr R.H. Varey who organised the CERL participation in the Gent campaign.

6. REFERENCES

Ames, D.L., 1979, Electrochemical cells for measuring ozone in air, CERL Note No. RD/L/N 2/79

Anderson, L.G., 1979, Effects of night-time chemistry on the transport of ozone and ozone precursors, J. Air Pollut. Control Assoc., 29, (9), 970-3

Broder, D., Dütsch, H.U. and Graber, W., 1981, Ozone fluxes in the nocturnal planetary boundary layer over hilly terrain, Atmos. Environ., 15, (7), 1195-1199

Calvert, J.G., 1976a, Test of the theory of ozone generation in Los Angeles atmosphere, Environ. Sci. and Tech., 10, (3), 248-256

Calvert, J.G., 1976b, Hydrocarbon involvement in photochemical smog formation in Los Angeles atmosphere, Environ. Sci. and Tech., 10, (3), 256-262

Chameides, W.L. and Stedman, D.H., 1976, Ozone formation from NO_x in 'clean' air, Environ, Sci. and Tech., 10, (2), 150-153

Cox, R.A., Eggleton, A.E.J., Derwent, R.G., Lovelock, J.E. and Pack, D.H., 1975, Long range transport of photochemical ozone in North-Western Europe, Nature, 255 (5504), 118-121

Davis, D.D., Heaps, W., Philen, D. and McGee, T., 1979, Boundary layer measurements of the OH radical in the vicinity of an isolated power plant plume: SO_2 and NO_2 chemical conversion times, Atmos. Environ., 13, (8), 1197-1203

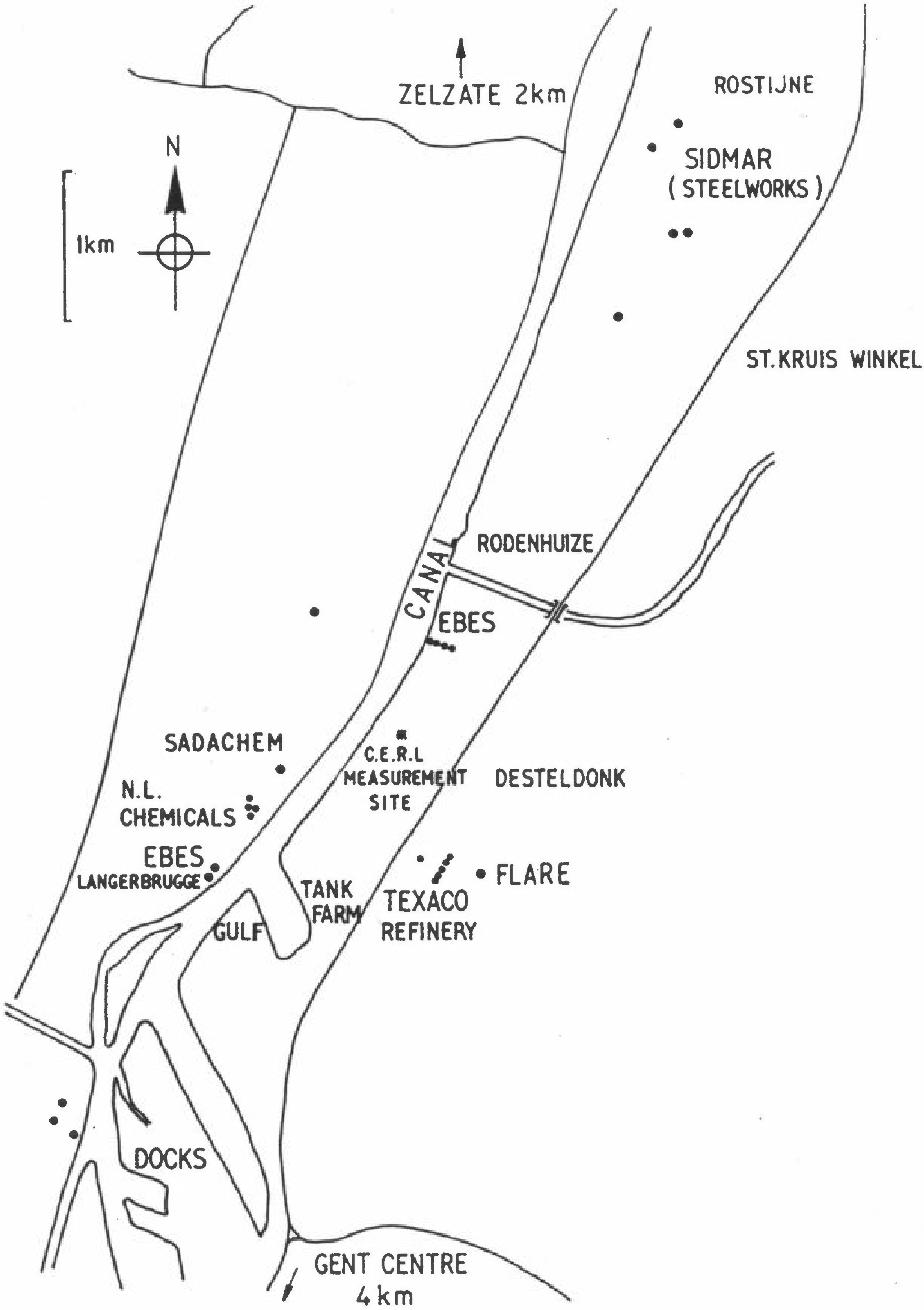


FIG. 1 IMPORTANT EMISSION SOURCES NEAR THE MEASUREMENT SITE

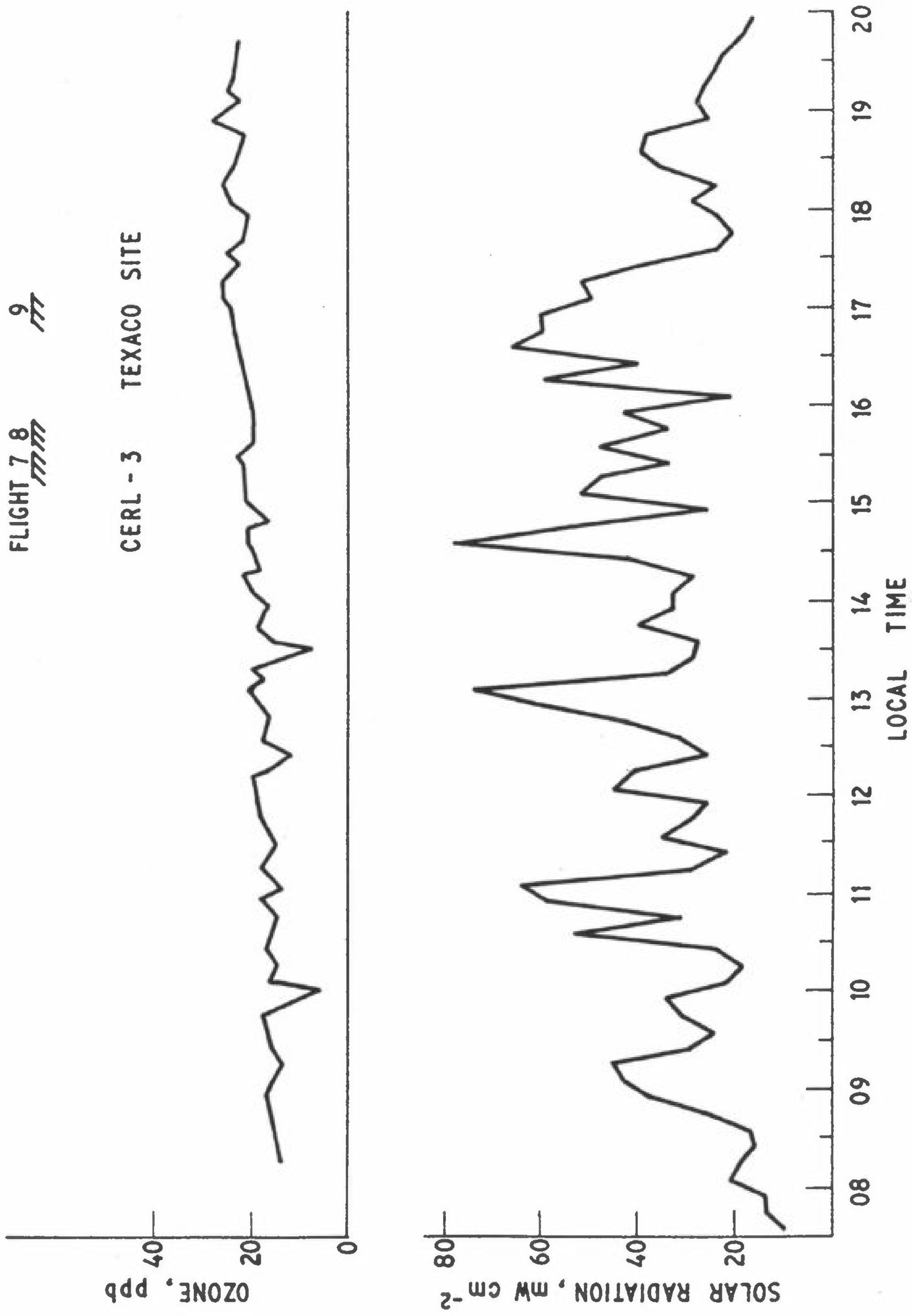


FIG. 13 MONDAY 22 JUNE GROUND LEVEL OZONE AND SUNSHINE RECORDS

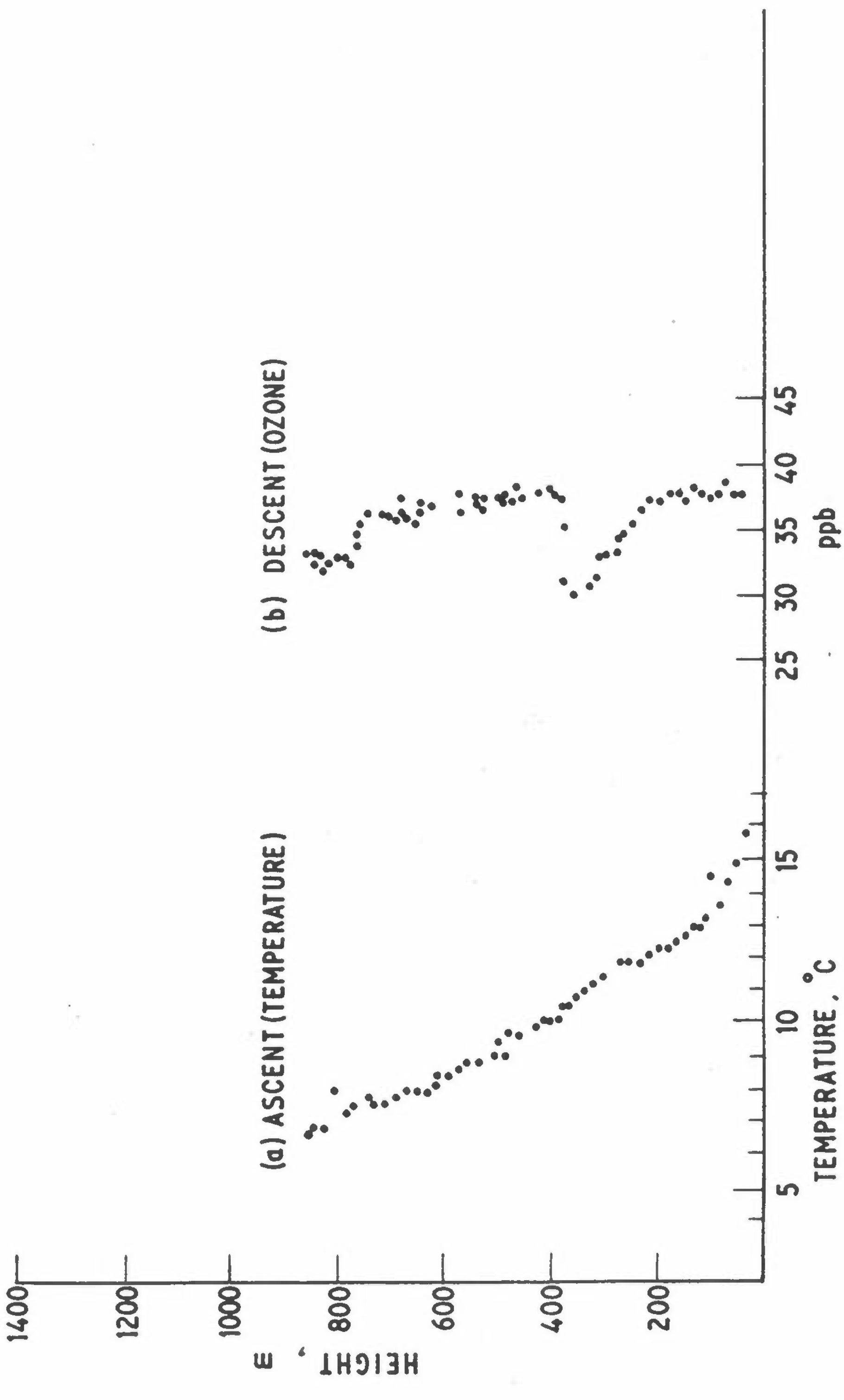


FIG. 14 FLIGHT No. 7 BEGINNING AT 15·15 ON MONDAY 22 JUNE 1981

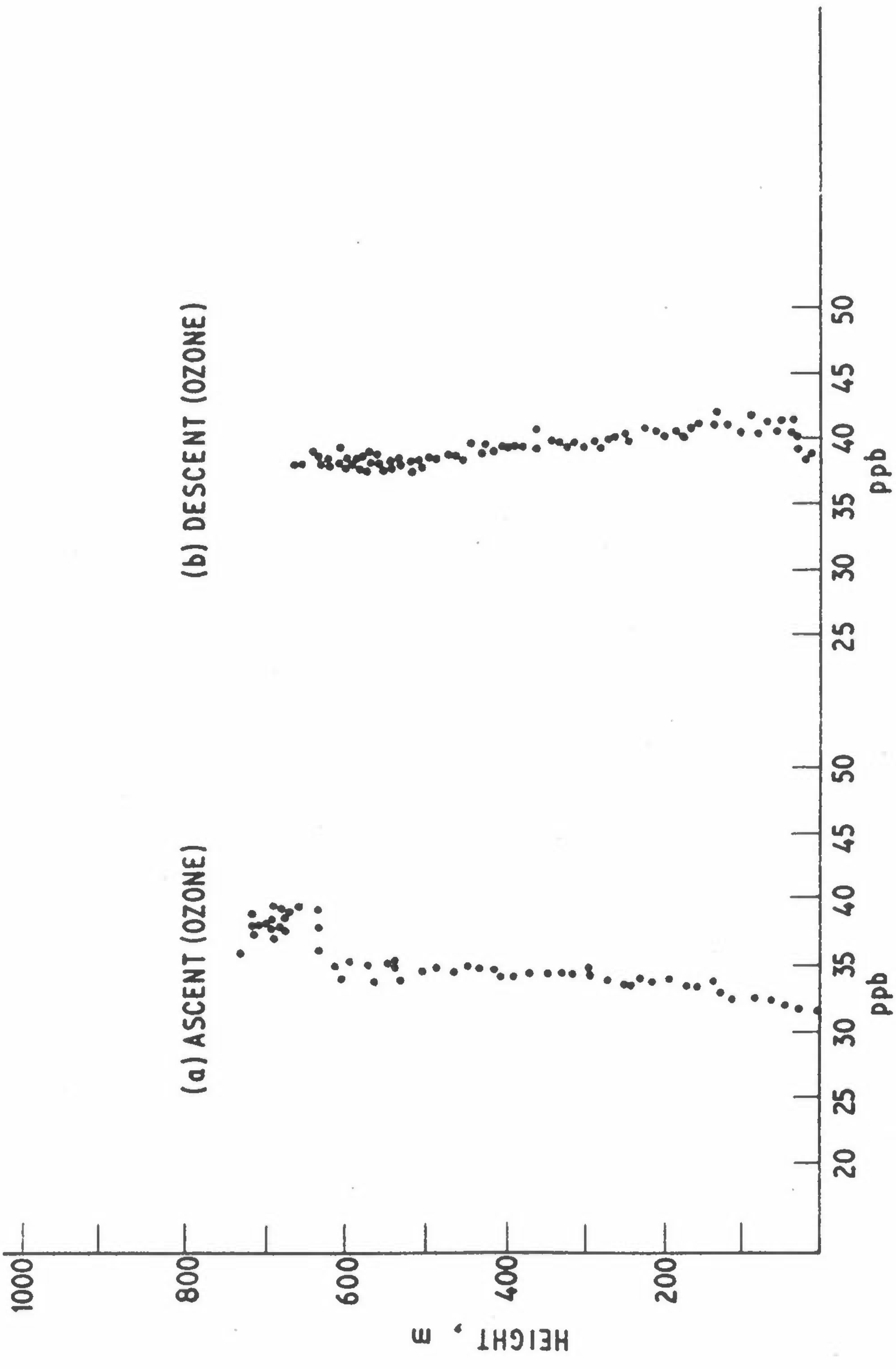


FIG. 15 FLIGHT No. 8 BEGINNING AT 15·35 ON MONDAY 22 JUNE 1981

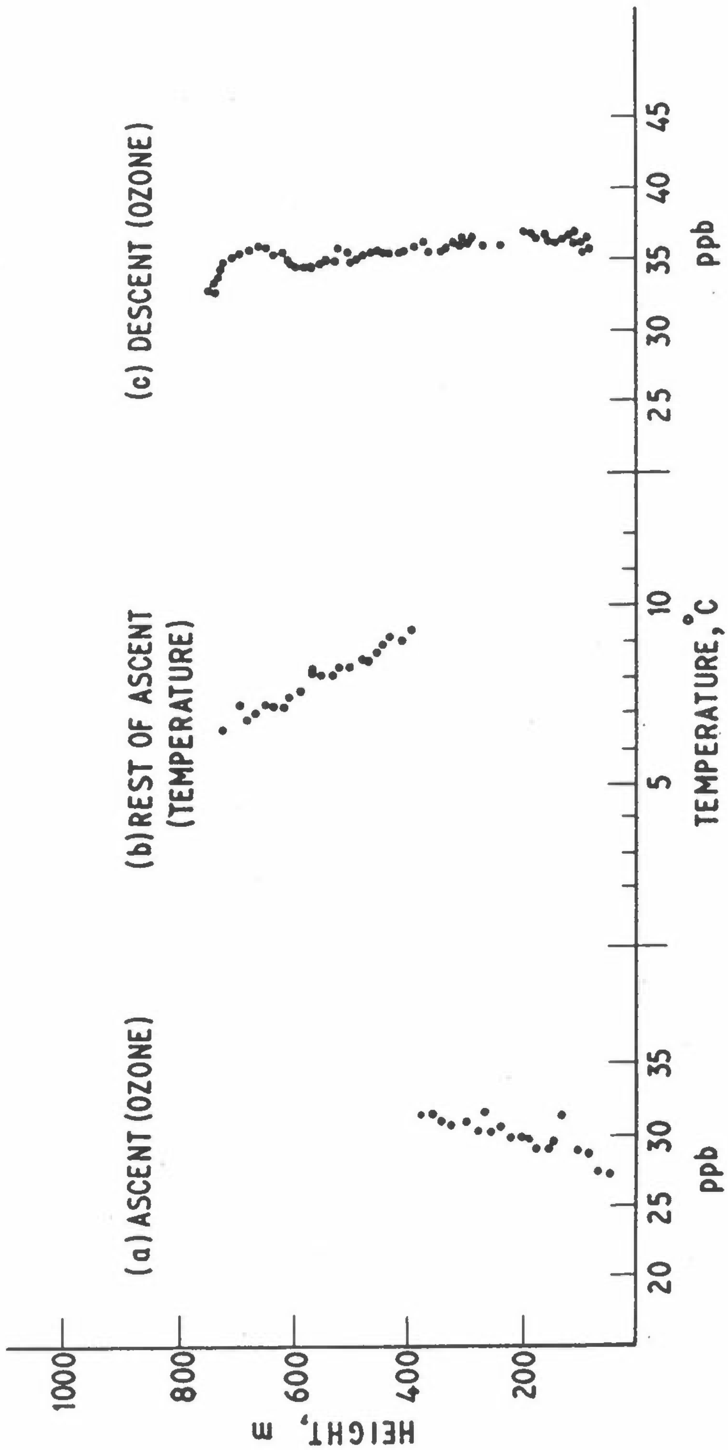
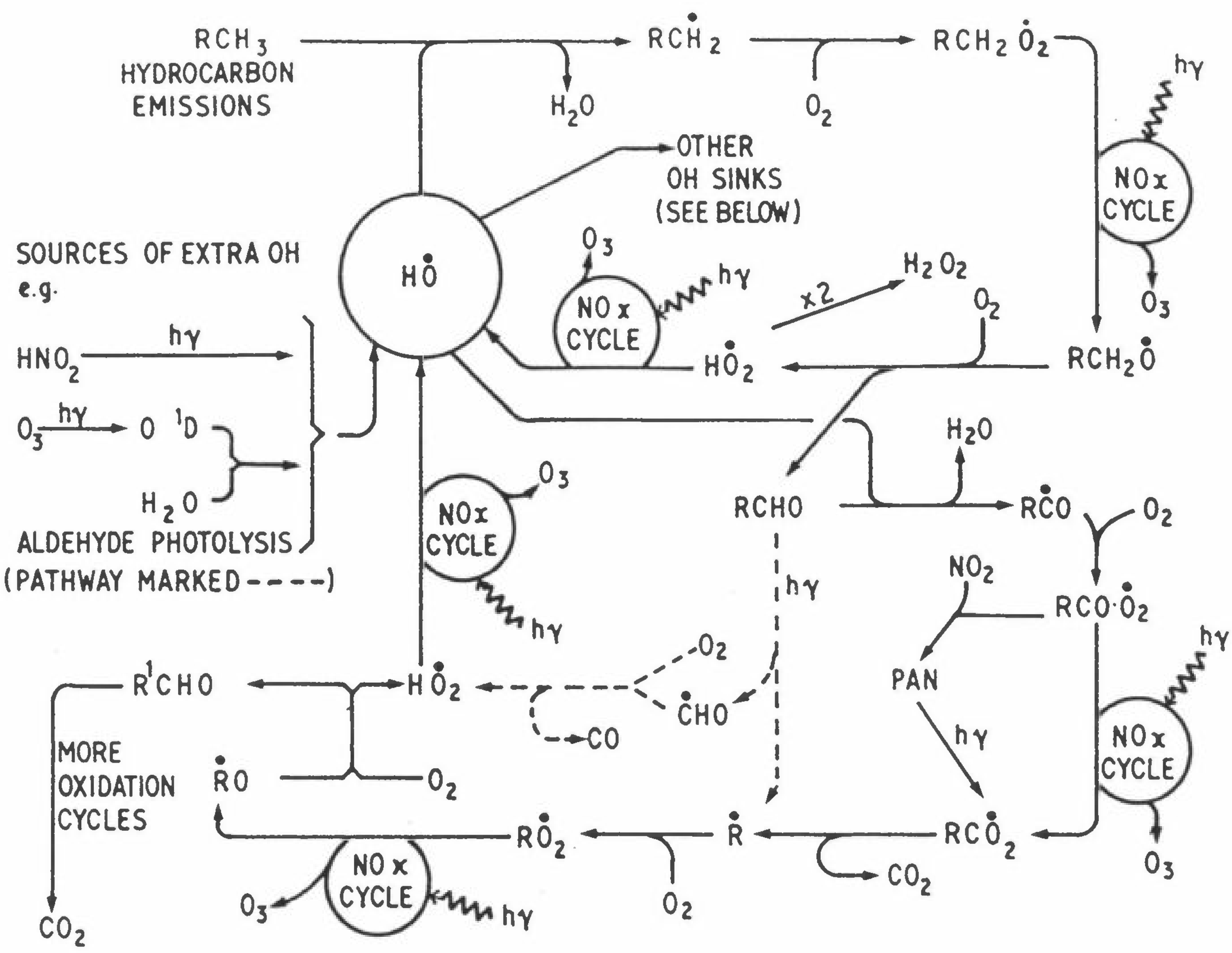


FIG. 16 FLIGHT No. 9 BEGINNING AT 16·52 ON MONDAY 22 JUNE 1981



THE NOx CYCLE

$NO_2 \xrightarrow{h\gamma \; (<395\ nm)} NO + O\,^3P$ ----- (1)

$O\,^3P + O_2 + M \xrightarrow{RAPID} O_3 + M$ ----------- (2)

$NO + O_3 \xrightarrow{RATE = k_3} NO_2 + O_2$ ----------- (3)

AND $NO + RO_2, HO_2\ etc \longrightarrow NO_2 + RO, HO\ etc.$

SOME REACTIONS OF THE OH RADICAL

(RATE CONSTANTS FROM GRAEDEL ET AL.,1976, EXCEPT THOSE MARKED *, FROM CALVERT 1976 b)

$HO + CH_4 \longrightarrow CH_3$	$k = 0.012\ ppb^{-1}\ min^{-1}$	$HO + C_2H_6 \longrightarrow R^\bullet$	$k^* = 0.39\ ppb^{-1}\ min^{-1}$
HO + n HEXENE	$k^* = 6.1$ " "	HO + 1 HEXENE	$k^* = 51$ " "
HO + BENZENE	$k^* = 6.6$ " "	$HO + CO \longrightarrow \dot{H} + CO_2$	$k = 0.21$ " "
$HO + CH_3CHO \longrightarrow CH_3\dot{C}O$	$k = 22$ " "	$HO + NO \xrightarrow{(+M)} HNO_2$	$k = 4.7$ " "
$HO + SO_2 \xrightarrow{(+M)} H\dot{S}O_3$	$k = 1.3$ " "	$HO + NO_2 \xrightarrow{(+M)} HNO_3$	$k = 6.5$ " "

$\left(\xrightarrow[\text{REACTIONS}]{\text{RAPID}} H_2SO_4 \right)$

FIG. 32 SIMPLIFIED OZONE PRODUCTION SCHEME

NORSK INSTITUTT FOR LUFTFORSKNING (NILU)
NORWEGIAN INSTITUTE FOR AIR RESEARCH
POSTBOKS 64, N-2001 LILLESTRØM

RAPPORTTYPE TEKNISK RAPPORT	RAPPORTNR. TR 10/90	ISBN-82-425-0215-3	
DATO NOVEMBER 1990	ANSV. SIGN.	ANT. SIDER 54	PRIS NOK 90,-
TITTEL Bruk av fjernstyrte fly		PROSJEKTLEDER S. Larsen	
		NILU PROSJEKT NR. E-90007	
FORFATTER(E) S. Larsen		TILGJENGELIGHET * A	
		OPPDRAGSGIVERS REF.	

OPPDRAGSGIVER (NAVN OG ADRESSE)

3 STIKKORD

Drone	Flymålinger	Prøvetaking

REFERAT

Rapporten omhandler resultat av litteraturstudier og innhentede opplysninger fra besøk og konsultasjoner med brukere

I hovedsak beskrives flytyper, styringssystemer, anvendelsesområder, måle- og prøvetakerutstyr.

Formaliteter knyttet til anvendelse av fjernstyrte fly er også beskrevet.

TITLE
Use of remotely piloted aircraft.

ABSTRACT

* Kategorier:	Åpen - kan bestilles fra NILU	A
	Må bestilles gjennom oppdragsgiver	B
	Kan ikke utleveres	C