AIRCRAFT–LABORATORIES FOR OPTICAL–METEOROLOGICAL AND ECOLOGICAL SOUNDING OF THE ATMOSPHERE

B.D. Belan

*Institute of Atmospheric Optics,
Siberian Branch of the Russian Academy of Sciences, Tomsk*
Received October 25, 1992

Instrumental complexes of aircraft–laboratories intended for sounding of the meteorological parameters, aerosol and gas composition of air, and underlying surface are considered in the paper. Intercomparison of specifications of different aircraft–laboratories including their measuring computer complexes are given.

Considerable possibilities of airborne techniques for investigation of the atmosphere and underlying surface are being increasingly employed by geophysicists from different countries in their routine practice. Nowadays there are several leads of airborne geophysical sounding. They differ either in the object being sounded (atmosphere, hydrosphere, and underlying surface) or in the problems to be solved, or in measuring techniques. Tens of different aircraft–laboratories (AL's) have been created. However, the information about the AL's published in the literature is incomplete and fragmentary and makes it impossible to judge the problem as a whole. The monographs and reviews,[1–4] that have been published previously, have not reflected the progress made in this field. Therefore, this paper is devoted to the comparison of the state of the art of the instrumental support for airborne techniques for geophysical sounding according to the data that have been published in the literature.

CLASSIFICATION OF THE AIRCRAFT–LABORATORIES

Several attempts to divide the aircraft–laboratories into types were undertaken in Refs. 3–7. In Refs. 3–5 the AL's were separated into universal, specialized, highly–specialized, and weather reconnaissance ones. In Refs. 8–9 the AL's for weather modification were additionally selected. Evidently, such a classification reflects only the problems to be solved by the AL's.

In our opinion, the sounding techniques used in airborne instrumentation complexes are no less important for classification of the AL's. The type of the aircraft–laboratory can change depending on the measuring technique when solving the same scientific problems. For example, the aircraft–laboratory intended for the determination of the aerosol composition of air can be equipped by both contact and remote sounding means. However, the AL's of the first and second types will differ not only in the composition and mounting peculiarities of the instrumentation, but also in the regime of flight.

In this connection we propose the division of the aircraft–laboratories into the following types. The specialized AL's, which are generally intended for the technological purposes and are far from the considered leads by their purpose and equipment, can be selected in a separate class. Such AL's were developed at the Flight Research Institute (FRI) of the State Scientific–Research Institute of Civil Aviation and other institutions for testing aircrafts, their individual units, etc. For example, the TU–154 aircraft–laboratory developed at the FRI was used for elaboration of the automated landing system of the BURAN shuttle spacecraft. Because this class of the AL's is far from the subject of this review, we will not further return to it.

The rest of the geophysical aircraft–laboratories can be divided into two groups by the character of the problems to be solved. The first group comprises the AL's intended for sounding of the underlying surface, the second – the AL's for the determination of various characteristics of the atmosphere. In each group we can distinguish several types of the AL's depending on the employed methods.

The first group comprises the AL's which use the natural optical, IR, and γ–radiation of the underlying surface. One can judge the characteristics of the underlying surface by the intensity and the spectrum of the selected radiation.

For the first time the aerophotography instrumentation operating in the optical spectral range has been used in this group of the AL's. Today this type of airborne sounding has been placed in commercial operation: corresponding enterprises and special–purpose AN–30 aircrafts have been created. The introduction of multispectral aerophotography became a logical elaboration of this type of the AL's. It made it possible not only to produce a map of the region, but also to tax forests, to detect tracts of diseased plants, to identify the oil films, etc.[8] A small series of the TU–134 SH AL's was produced to implement this type of the aerophotography.

The spectrophotometric and radiometric aircraft–laboratories,[9–13] whose instrumental complexes operate in the optical and IR wavelength ranges, are related to the second type of the AL's. They are intended to image the underlying surface in different spectral ranges in real time. A complex of applied problems including the determination of the radiative surface temperature is solved on the basis of the obtained data.

The aircraft–laboratories of the third type equipped with the instrumentation for γ–photography, which use the passive remote measuring techniques, are also related to the two above–described types of the AL's. With corresponding data processing such aircraft–laboratories are capable of determining not only the radioactive contamination of the region, but also the snow and water capacity of the inspected regions.

Later the aircraft–laboratories, which also could be related to this type, were equipped with active means for sounding of the underlying surface. Among these were nonmeteorological radars (meteorological ones appeared onboard the aircrafts much earlier) and lidars.[15–17] The AL's of this type are capable of determining the water capacity of the upper layer of the soil, the turbidity and

0235-6880/93/01 1-18 $02.00

the height of the waves of the ocean, the height of trees, the presence of pollution on the underlying surface, etc.

The common property of this type of the aircraft–laboratories is that all their measuring complexes are directed in the nadir and, as a rule, do not carry out the measurements at the flight altitude.

Let us relate the AL's intended for the study of the atmosphere irrespective of the employed measuring techniques to the second group of the aircraft–laboratories. All variety of such AL's can be divided into three types. The first type comprises the aircraft–laboratories equipped with contact sensors (they were historically the first). The second type comprises the aircraft–laboratories which implement active and passive remote methods. And the third type comprises the AL's with the combined equipment. They have made their appearance in the last decades. These AL's have both contact and remote measurement means. The specific application of the AL of any of these three types can be different. It can be intended for weather reconnaissance, cloud investigation, weather modification, study of typhoons and volcanic eruptions, etc.

SPECIFICATIONS OF THE AIRCRAFTS INTENDED FOR THE DEVELOPMENT OF THE AIRCRAFT–LABORATORIES

The performance of the AL depends not only on the specifications of its scientific instrumentation, but also on the quality of the aircraft carrying this instrumentation. When creating the aircraft–laboratory, after determination of the class of problems to be solved, it is necessary to select the type of the carrier which provides for their solution.

The most important specifications of the carrier, which must be taken into account first of all, are the time and range of flight, which determine the range of action of the AL, and minimum and maximum flight altitudes which determine the altitude range of the AL operation and, correspondingly, the class of problems to be solved. For example, the γ–photography requires the flight altitude as low as possible,[14] but the stratospheric investigations, on the other hand, require the maximum altitude.

When selecting the carrier, the cruising and working (during the course of sounding) speeds of the aircraft are taken into account. It is important for setting up the experimental procedure. Thus, for a fixed bit rate onboard the AL, the less is the working speed of the aircraft, the higher is the spatial resolution. The increase of the frequency of measurement of the AL increases the number of technical problems which must be solved for carrying out *in situ* contact measurements. First of all, they are the problems of extreme heat of the temperature sensors due to the complete deceleration of air, fulfilment of the isokinetic condition of air sampling, and protection of sensors from mechanical damage in the forward flow.

The aircraft power supply, load–carrying capacity, rent, tightness, volume and comfort of the cabin, and the presence of the design elements which provide for mounting the scientific instrumentation are very important for the selection of the carrier.

At present more than 50 types of carriers have been utilized all over the world beginning with gliders and single–engine piston aircrafts and ending with large transport jet air–liners of last generation. The specifications of the most part of these carriers are summarized in Table I. In addition to the carriers listed in Table I, the AL's have been developed on the basis of the B–23, B–707, B–727, B–747, C–90, C–131, C–160, Dornier–128, ND–34, T–28, and MB–57F (WB–57F) aircrafts. However, the specifications of these aircrafts have not been reported.

Summarizing the foregoing prior to the analysis of the data of Table I it should be noted that in the ideal case the development of the aircraft–laboratory requires the aircraft which can fly for a long time and correspondingly has a long range of action, can fly at an altitude of several tens of meters and climb to the stratosphere. It must be economic and inexpensive, its cabin must be comfortable and large, and its cruising speed must be high while its working speed low. The glider must be quite handy for mounting the instrumentation.

The AN–12, AN–30, C–130, CV–990, DC–6, DC–7, DC–8, IL–14, IL–18, L–188 Electra, and WP–3D Orion aircrafts are ideally suited to the enumerated requirements. Judging by the references, they were most often utilized for development of the aircraft–laboratories.

The development of the AL's on the basis of such carriers as AN–2, Cessna–206, and L–200 was hardly effective. Usually such aircrafts are used due to low rent and simplicity of mounting the nonstandard equipment. As a rule, they are utilized provisionally. For example, the AL of the West Siberian Regional Scientific–Research Institute of Hydrology and Meteorology (RSRIHM) on the basis of the AN–2 aircraft operated only one year and was intended for investigation of the turbulence in the boundary atmospheric layer.[18]

Only one specification of the carrier is important for some problems. Thus in the study of the stratosphere we must raise instrumentation as high as possible. This dictates the utilization of such aircrafts as ER(U–2), F–106, and IL–28.

PLACEMENT OF THE INSTRUMENTATION ONBOARD THE AIRCRAFT–LABORATORY

The peculiarity of the airborne measuring technique is that the devices placed onboard or outside of the AL must operate under extreme conditions of intense vibrations, large temperature and humidity gradients (especially in winter), high rates of air flow around the sensors, g–load caused by the turbulence, precipitation, icing, and intense pickup from the standard equipment.

Three variants of the placement of the scientific instrumentation onboard the aircraft are possible depending on their application. These variants take into account the enumerated problems.

Usually the control and recording instrumentation and secondary converters are positioned in the aircraft cabin on special tables and racks which provide their fast and reliable fastening to the aircraft construction and creates no problems.[19] The sole exception is the problem of protection from vibrations, since even in the places most distant from the engine the vibrations are rare less than 0.1–0.2 mm (see Ref. 20). This problem is partially solved by using dampers (thereby weakening the effect of vibrations by a factor of 1.5–2), plugs, and connectors. It is natural that the placement of the instrumentation along the cabin should be made on account of position of the center of gravity.

The second variant of the placement of the equipment is connected with the need to bring the laser beam in and out of the aircraft when using the active and passive remote sensing means. As in the first case, the receiving and transmitting units of these devices are

TABLE I. Specifications of the aircraft–carriers of scientific instrumentation.

Aircraft	Engine type	Number of engines	Speed, km/h	Maximum altitude, m	Flight time, h	Flight range, km	Fuel consumption	Cost of one–hour flight
1	2	3	4	5	6	7	8	9
AN–2	*P*	1	250/200	4300	4	750	–	500 roubles*
AN–12	*T*	4	600/550	9700	6.5	3500	–	3000 roubles*
AN–24	*T*	2	500/450	9000	5.5	2200	–	1500 roubles*
AN–26	*T*	2	500/300	8600	6	2800	550	1500 roubles*
AN–30	*T*	2	450/250	8100	6	2700	500	1500 roubles*
B–737	*J*	2	960/420	10000	6	3800	–	–
C–130	*T*	4	550/–	11000	12	5500	1820	$ 1800
Caravelle–116	*J*	2	825/700	12000	5.5	3500	–	–
Cessna–206	*T*	1	320/290	8000	4	1200	–	–
Cessna–404	*P*	2	420/370	8000	6	1800	–	–
Cheyenne–400	*P*	–	580/–	–	7	3500	230	$ 350
CV–990	*J*	4	950/–	13500	7	4800	–	–
DC–6	*P*	4	580/360	6000	12	7900	–	–
DC–7	*P*	4	450/–	7000	24	9000	–	–
DC–8	*J*	4	850/–	10000	12	11000	4800	$ 5400
Dornier–28	*P*	2	280/–	8900	7	1700	–	–
Dornier–228	*T*	2	430/320	9000	–	–	–	–
ER–2 (U–2)	*J*	1	970/–	22000	–	–	–	–
Falcon–E	*J*	2	920/850	–	6	3500	–	–
Fokker–27	*T*	2	500/–	9200	6	2000	–	–
F–106	*J*	1	2300/–	16000	2.5	2400	–	–
Gulfstream–IY	*J*	2	850/–	13100	9	6300	1120	$ 1200
IL–14	*P*	2	400/200	7000	10	3200	360	470 roubles**
IL–18	*T*	4	685/300	13000	12	5000	800	2800 roubles*
IL–28	*J*	2	900/700	16500	4.5	2500	–	–
IL–76	*J*	4	900/850	13000	11.5	4800	7200	9000 roubles*
King Air	*T*	2	450/400	8500	7	2300	–	–
KC–135A	*J*	4	630/–	12000	9	–	–	–
L–188 Electra	*T*	4	580/–	9500	11	4500	1820	$ 1800
L–200	*P*	2	310/280	5000	5.5	1700	–	–
Learjet–36A	*J*	2	800/–	15000	8	5000	490	$ 700
Queen Air	*P*	2	400/300	9000	6.5	2300	–	–
Saberliner	*J*	2	720/–	15000	4	2200	820	$ 700
TU–16	*J*	2	1000/800	13000	8	6400	–	–
TU–104	*J*	2	1000/800	13000	6.5	4200	3400	–
TU–134	*J*	2	800/650	13000	4.5	2400	–	2400 roubles*
TU–154	*J*	3	1000/900	13000	6.5	5000	–	3600 roubles*
Twin Otter	*T*	2	300/240	3000	4.5	1300	–	–
WP–30 Orion	*T*	4	580/360	12000	18	6600	2045	$ 1800
WC–130B	*T*	4	600/480	12000	11	–	–	–
YAK–40	*J*	3	750/600	12000	4.5	2000	–	1600 roubles*

Note: Lack of information (dash), piston–type engine (*P*), turbo–prop engine (*T*), jet engine (*J*), * and ** stand for the price of 1991 and 1988, and 250/200 stands for cruising speed/working speed (during the course of sounding).

placed in the cabin in front of the hatches providing the passage of the radiation being measured. In addition to the above–indicated measures of protection from vibrations, the problems arise connected with the changes to the construction.[19] The size of the hatches allows no cut off or distortion of the field of view or of the directional pattern of the receivers. At the same time, the hatches must protect the instrumentation and the experimenter from the atmospheric effects and allow no reduction in the strength of the glider construction. These questions are easiest to solve in the specially elaborated AN–30 and TU–134 SH aircrafts or in the nonhermetic AN–2 and IL–14 aircrafts equipped with the standard glazed or open (unglazed) hatches. In this case the problem of the installation of the equipment reduces to the development of the means of fastening, to the change of the existing windows by the required ones or to the creation of the hermetic containers enclosing the instrumentation placed above the open hatches in the case of the hermetic cabin. The creation of additional hatches in available gliders involves significantly hard elaboration of the aircraft and its testing which is possible only in the industrial conditions.

The third variant of the placement of the equipment onboard the aircraft is caused by the need of placing various sensors and fairings outside the aircraft. For solving this question it is necessary to consider two things, namely, suitable placement of the sensors on the aircraft covering and keeping the tightness of the cabin at its integrity. The first is connected with the neutralization of the turbidity effect of the medium and of the aircraft itself on the measurement results, the second is determined by the flight safety.

The suitable placement of the sensors must take into account the aerodynamic characteristics of the aircraft hull. Thus, the study of readings of the temperature sensors placed in different parts of the IL–14 aircraft, performed by the scientists from the Central Aerological Observatory (CAO), showed that for the sensors placed in front of the propellers, in spite of the considerable distance between them (up to 6 m) and the wide range of variation of their distances from the covering (10...80 cm), the difference between the readings was no more than +0.03...0.05°C, i.e., the measurement error.[21] For the sensors placed behind the propellers the difference between the readings exceeded +0.2...0.3°C, which was greater than the measurement error.

Mounting of the remote sensing means placed outside the hull is related to the third variant. An example of such a mounting is the radars enclosed in the containers, which have the shape of the suspended fuel tanks, and mounted on the pylons of the TU–134 SH aircraft–laboratory.[19]

As a rule, the aircraft–laboratories are unique, in rare cases there may be two or three copies. In addition, the initial problems to be solved can change with time. For these reasons it is desirable for the AL to provide rapid change of the equipment in order to eliminate demurrages of the AL. This imposes some requirements on the constructional features of the instrumentation. For example, the same containers for the remote sensing instruments have the modular structure for a long time.[22] It makes it possible to change easily the instrumentation composition, to adjust and test it in the field rather than in industrial conditions.

Thus, all changes during mounting of the scientific equipment when creating the aircraft–laboratory are related only to the inner and external parts of the hull. All standard systems of power supply, communication, life–support, navigation, etc. remain unchanged or improve during the mounting process.

SCIENTIFIC INSTRUMENTATION COMPLEXES OF THE AIRCRAFT–LABORATORIES

Although the selection of the specifications of the carrier and the peculiarities of the placement of the research instrumentation onboard the AL's are important, the efficiency of using the aircraft–laboratories is determined primarily by the composition of devices and by the employed measuring methods.

In Refs. 3 and 4 the complex of the AL scientific instrumentation is divided into the following groups according to the functional capabilities:

– airborne devices for measuring the physical characteristics of the environment (primary converters or sensors),

– means of recording and control of the sensor operation (secondary converters),

– airborne systems of data recording and processing,

– aerophotography and TV instrumentation,

– additional navigation and pilot equipment, and

– auxiliary equipment.

In its turn according to the application, the measuring complexes are divided into the following groups[3,4]:

– thermodynamic devices for measuring the mean values and the fluctuations of the meteorological parameters (pressure, temperature, humidity, and wind speed and direction) at the flight altitude,

– cloud measuring devices for the study of the microstructure of clouds and precipitation,

– radars and lidars,

– radiative actinometric devices,

– electrometric devices intended for measuring the atmospheric electric field strength, the aircraft charge, etc., and

– gas analyzers.

However, since the publication of these reviews the interests of geophysicists have been essentially changed, and consequently the orientation of the experiments and the instrumental base have been changed too. First of all, it is related to the following groups.

Instead of the devices intended for the study of clouds it is more appropriate to say about aerosol complexes, since solving the problems of atmospheric optics and monitoring of pollution resulted in the fact that the most part of the airborne experiments is carried out under clear air conditions. As a result, photoelectric counters, electrostatic analyzers, and diffusion batteries, which expand the range of the measurable particle size toward smaller size (1–3 nm), came into being onboard the AL's. Thus, the cloud measuring devices are included into the aerosol complexes.

The progress in the development of the airborne laser radar and radar techniques resulted in their formation into the independent leads. The investigation was performed with the use of special aircraft–laboratories. At present there are the AL's which are equipped only by one kind of the active sensing systems, for example, the IL–18 AL's of the Institute of Radio Electronics (IRE) of the Russian Academy of Sciences[23] use several radar complexes, but the NASA F–106 aircraft–laboratory has only one lidar.[15] So, it is expedient to divide this group into two individual groups.

The same is related to the radiative actinometric group. In recent years the instrumentation for radiative and microwave measurements has been intensively

TABLE II. Summary table of measuring systems used onboard the aircraft–laboratories.

System	Type	DC–6	WC–130B	KC–135	CV–990	L–188	WP–3D	Sabreliner	Queen Air	C–130	DC–7	YAK – 40	Cessna – 202	C–131A	King Air	ER–2	DC–8	Caravelle 116	Falcon	Twin Otter	Cessna 404	FSRC CAO	IL–14 MGO	IL–18 DOR	AN–30 IAO
Navigation system	Inertial	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	DISS	+	+	+	+	+	+	–	–	+	+	+	*u*	*u*	*u*	*u*	+	*u*	*u*	+	+	+	+	+	+
	OMEGA	+	+	–	–	–	+	–	–	+	+	–	*u*	*u*	*u*	*u*	+	*u*	*u*	–	–	–	–	+	–
Meteorological system	Mean parameters	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	Fluctuations	+	–	–	–	+	+	–	+	+	–	–	+	–	–	–	–	–	+	+	–	+	+	–	+
Aerosol complex	Clouds	+	+	–	–	+	+	+	–	+	–	+	–	+	–	–	–	–	–	–	–	+	+	–	–
	Water content	+	+	–	–	+	+	+	+	+	+	+	–	–	–	–	–	–	–	–	–	+	+	–	–
	Clear atmosphere	+	–	–	–	+	+	–	+	+	–	–	+	+	+	+	+	+	–	–	–	+	–	–	+
Gas–analysis complex	Gas analyzers	–	–	–	+	+	+	–	+	+	–	–	+	+	+	+	–	+	–	+	+	+	–	–	+
	Gas chromatograph	–	–	–	–	+	+	–	–	+	–	–	–	+	–	+	+	+	–	–	–	–	–	–	+
	Total content	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	–	–	–	–	–	–	–
Radiometer (microwave)		+	–	–	+	+	+	–	+	+	+	–	–	–	–	+	–	–	–	–	+	+	+	+	+
Optical Complex		–	–	–	+	–	+	–	+	–	–	+	+	+	–	+	+	+	–	–	–	+	+	+	+
Lidar		–	–	–	+	+	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	+	+
Actinometer		+	+	–	+	+	+	+	–	+	+	–	–	+	+	+	–	–	–	+	–	+	+	+	–
Electrometer		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	+	+
Recording system (computer)		+	+	*u*	+	+	+	*u*	*u*	*u*	*u*	+	*u*	+	*u*	*u*	*u*	*u*	*u*	*u*	*u*	+	+	+	+

Note: Here u means unspecified.

developed, while the actinometric devices have been slightly modified. The radiative sensing has become an individual lead[24] along with radar and laser radar techniques.

A group of devices, which has been increasingly employed onboard the AL's in recent years, is lacking in the proposed classification.

These are the devices intended for measuring the optical parameters of air: nephelometers capable of determining the aerosol extinction coefficient, mass concentration of suspended substances, and visual range; spectrophotometers capable of measuring the optical depth of air column in different wavelength ranges; and, the transparency meters.

Therefore, at present the classification reported in Refs. 3 and 4 must be supplemented and refined.

The data on the various measuring systems placed onboard the aircraft–laboratories, which have been most intensively employed and are now in use, are summarized in Table II.

It follows from Table II that there is not any aircraft–laboratory, even the most universal one which includes all the types of the measuring systems. Even the Flight Center of the Central Aerological Observatory (CAO) with the instrumentation of all its aircraft–laboratories has not all possible systems. Each concrete CAO aircraft–laboratory has much smaller number of sensors and devices. This number is determined by the character of the experiment.[25]

From the complexes tabulated in Table II the NASA L–188 Electra,[26–29] NOAA WP–3D Orion,[30] and C–130 (England)[31–32] have the largest number of devices. The Optik–1 ÉM AN–30 aircraft–laboratory of the Institute of Atmospheric Optics (IAO) of the Siberian Branch of the Russian Academy of Sciences[33] approaches them in the number of systems. The other aircraft–laboratories are equipped by the smaller number of devices reflecting their specialization.

However, two systems are included in all the AL's tabulated in Table II. They are the inertial navigation system and the meteorological system capable of measuring the mean values of the meteorological parameters. Generally speaking, the aircraft cannot fly without the first system. The correct interpretation of the data is impossible without the second system irrespective of the problems being solved. It is no mere chance that the parameters measured by these systems are included in the list of the basic parameters recommended by the World Meteorological Organization (WMO) for both multipurpose and specialized aircraft–laboratories.[34,35]

There are relatively few aircraft–laboratories equipped by lidars in Table II. To be precise, it should be noted that only standard lidars are summarized in the table. Actually, there are much larger number of lidars, but they are used, as a rule, in individual experiments, or are placed onboard the aircraft without any other scientific instruments, and it is unlikely to say about the aircraft–laboratory.

Let us briefly analyze the devices included in the enumerated systems.

PILOT AND NAVIGATION EQUIPMENT

The LTN–51 or LTN–72 inertial navigation systems are placed onboard all the foreign long–range AL's.[36] These systems are capable of measuring and double integrating the linear and angular accelerations of an aircraft and using these data as a base of calculating the ground speed, drift angle, and dead reckoning as well as of measuring and differentiating the pitch, bank, and course angles. The systems include computers which continuously generate the running aircraft coordinates and the navigation data for guiding the aircraft to the preselected eight stations on the route. The OMEGA radionavigation system is placed onboard some AL's in order to correct the errors (1.5 km/h) of an inertial navigation system accumulated during many–hour flights. This system uses the phase method of measuring the coordinates by means of three transmitting stations operating in the frequency range 10.2–13.6 kHz. In this case the accuracy of determining the coordinates reaches 0.1 km. The GPS NAVSTAR system has been tested onboard the foreign AL's in the last few years. This system uses the satellite referencing and is capable of determining the horizontal coordinates to an accuracy of 5–25 m and the flight altitude to an accuracy of ~ 15 m (see Ref. 37).

The standard navigation system without computer is usually used onboard the domestic AL's. Therefore, the location of the aircraft is determined much more roughly with this system. The system for determining the aircraft coordinates by the KVITOK satellite has been developed and used in the last few years. However, we could not find the data on its specifications in the available literature.

As a rule, the aircraft–laboratories are equipped with the Doppler radars for measuring the ground speed and the drift angle. Domestic aircraft–laboratories are equipped with the DISS Doppler radars for drift velocity measuring. Abroad the Decca–Navigator systems are used. The data of the Doppler radars are used for determining the aircraft location and calculating the wind speed and direction.[38]

In the AL's with airborne recording systems the navigation characteristics are stored on the external information medium simultaneously with the physical parameters. Further it makes the data processing essentially easier.

GAUGES OF THE METEOROLOGICAL PARAMETERS

As has already been noted above, all the aircraft–laboratories have meteorological systems. They use both unified devices and experimental models.

Airborne measurements of total and static pressure are carried out by means of air pressure gauges (APG's) fabricated in the form of the Pitot tubes and loaded on a barochamber.[39] As a rule, each aircraft has several APG's to compensate for spoiling the flow around the hull while manoeuvring. The APG's on the domestic aircrafts are loaded on the standard pressure gauges with instrumental compensation for the temperature deviations in accordance with the model of the standard atmosphere.[39] The system terminates in an indicator. The error in measuring the pressure by the domestic systems[5] is 1–2 mbar. Almost all the foreign AL's have the Rosemount Inc. gauges installed after the APG's. Their secondary converters are connected with an airborne computer performing averaging of the data which are then used in all calculations.

Pressure is determined with an error of 0.5–1 mbar depending on the type of the gauge.

The main type of the temperature gauges used in modern AL's is the eddy–proof resistance thermometers. The Rosemount Inc. platinum gauges are placed onboard the Electra,[26–29] WP–3D,[30] Falcon,[32] and some other aircrafts. They make it possible to measure temperature with an error of 0.5–1°. Sometimes thermistors are used, for example, the YSI/MPI gauge onboard the Cessna–206 AL.[40] The serial airborne gauges of temperature were not produced in the former USSR. Therefore, the domestic AL's use the experimental models. The CAO electrometeorograph placed onboard several AL's of the State Commitee on Hydrology and Meteorology (SCHM) is most widely used.[41] It is capable of measuring the temperature in the range –70...+50°C with an error of ±0.4°C. The standard airborne gauges give an error of no less than 2°, according to the data reported in Ref. 42.

The condensation hygrometers or dew–point hygrometers, or more rarely hygristors are used onboard the foreign aircraft–laboratories for measuring air humidity. Individual AL's have two or three gauges of different types. The Falcon[43] AL has the Vaisala HMP–11 hygristor and the Normalair Garrat IDO–1 βLR Electronic Research Corp. condensation hygrometers. It could be specially noted that foreign industry offers a broad assortment of hygrometers to the scientists. The EG86 gauge is placed onboard the Sabreliner[44] and Cessna–404 Al's.[45] The Cambridge System–137 hygrometer[46] is used onboard the Queen Air AL. The WP–32 AL uses the General Eastern Inc. hygrometer.[47] The Lyman–α optical hygrometers of the UV range have been widely used onboard the foreign aircraft–laboratories in the last few years. They are placed onboard the Electra,[26] Cessna–404 (as a second device[45]), and Sabreliner[36] AL's. Hygristors are used onboard the Queen Air (Germany)[48] and L–200V[49] Al's. The measurement error of the above dew–point hygrometers is 0.5–1° with a time constant of 2–3 s. In addition to the hygrometers, many foreign AL's use the devices measuring the fluctuation of the air refractive index. They are microwave radio refractometers used for obtaining the data on humidity pulsations.

In the former USSR, in contrast to the foreign countries, the problem of measuring the humidity has not yet been solved. Most frequently in the domestic AL's the relative–humidity gauge, in which the animal tissue is used, is taken from radiosondes. But such a gauge has low sensitivity at negative temperatures.[41] Therefore, the AL's use, as a rule, the experimental complexes or the laboratory instruments, for example, the Volna or GS–210 hyghometers onboard the IL–14 aircraft of the Main Geophysical Observatory (MGO). And obviously they will not be improved in the nearest future.

According to the data summed up in Ref. 3, the NCAR Gust Probe system was used previously onboard the L–188, WP–3D, Sabreliner, Queen Air, and C–130 aircraft–laboratories for measuring the turbulent characteristics. This system includes the sensors of acceleration and instantaneous angles of attack and slip of an incoming flow (spring–loaded or unloaded wind vanes) and gauges of the total and static pressure, temperature, and air refractive index. All sensors are mounted on a special rod placed ahead of the aircraft in the zone of the unperturbed flow. The exceptions are the acceleration sensors placed inside the rod. The system has its own computer which receives the data from its own sensors and the sensors of pilot and navigation complex: gyrovertical, heading gyroscope, inertial or Doppler radar navigation system, and pressure gauges. The Gust Probe system was capable of recording the fluctuations of all wind velocity components, temperature, and humidity in the frequency range 0.02–10 Hz. Later this system was replaced by modern systems, namely, the DISA Triaxial R91 system used onboard the Falcon[27] and Rosemount Inc. system used onboard the Sabreliner.[44] The domestic AL's use the experimental models, for example, the ASTA system is used at the Flight Research Center of the Central Aerological Observatory[4,5] (FRS CAO) and the TUZ–1 and BORT–1 systems –– onboard the MGO IL–14.[50] These complexes are capable of extending the frequency range of recording up to 100 Hz and to increase the accuracy of measurement of the fluctuations of the meteorological parameters.

The wind speed and direction are determined onboard the AL by calculational method which use the aircraft itself as a source of data.[51] It follows from the analysis of the velocity field of the flying aircraft that its velocity vector relative to the air mass (true air velocity **V**) and the velocity vector of the air mass relative to the ground (**v**) add up to the aircraft velocity relative to the ground (**w** – ground velocity), according to the principle of the so–called navigation triangle. Various methods are used for measuring the air velocity **V** of the aircraft. Nevertheless, both foreign and domestic AL's use the manometric method,[52,53] which requires the correction of the measured value for the air compressibility. As has already been noted above, the ground velocity **w** is measured onboard both domestic and foreign aircrafts by means of the Doppler systems.[38] The vector **v** is easily calculated from the known magnitudes of **V** and **w**. The available accuracy of the determination of the wind characteristics depends primarily on the type of the employed pilot navigation equipment and ranges from 0.05 to 2° for the direction and from 0.01 to 3 m/s for the speed.[5,54]

AEROSOL COMPLEXES

As a rule, airborne complexes for investigating the atmospheric aerosol include a number of devices capable of measuring the mass concentration and the number density of aerosol particles, their chemical and dispersed composition, and morphology both under cloudy and clear–air conditions. To do this, one use both routine devices and various samplers which require subsequent laboratory analysis. We consider here only the most frequently used devices disregarding the correctness of airborne sampling since it is a problem of special comprehensive review.

The foreign AL's use, as a rule, the ASASP, ASSP, and FSSP photoelectric counters of different modifications in order to measure the number density and dispersed composition of aerosol particles (outside of clouds). The counters of this series are placed onboard the Queen Air,[34] WP–3D,[30] C–130,[31] and Fokker–27.[55] The production of such devices developed abroad makes it possible to use the other devices onboard the AL's. So, the TSI–3030 and Royco–218 counters were used onboard the Cessna–206,[46] Mee Inc. counters were used onboard the DC–6,[34] and RION KC–01 counters were used onboard the Cessna–404.[45] The AZ–5 counter or its modifications are typically used onboard the domestic AL's.[41]

Various samplers capable of depositing the aerosol on filters or substrates for subsequent laboratory analysis are placed onboard the AL to determine the chemical composition and the morphology of particles. As a rule, all these devices are the experimental models and are unique or produced in several copies. The AFA–VP, HA, and HP filters of different size made of the FPP–15 textile are most often used onboard the domestic AL's. The Nylon, Millipore, and Whatman 40 and 41 textiles are used abroad. The best analytical methods are used for their laboratory analysis.

A start of the airborne investigations of aerosol has been made from clouds. Therefore, the large number of various devices have been developed for these purposes at present.[41] However, there is a leader in this area. This is the Particle Measurement System (PMS) firm (USA). The systems of this firm are placed onboard almost all foreign AL's. Since the PMS complex includes several devices, this system solves completely the problem of measuring the aerosol dispersed composition in the particle size range 3...4500 μm.

The domestic AL's use primarily the experimental equipment. Among these are the Aspect 10 and 11, Aėlita developed at the Institute of Experimental Meteorology (IEM),[41] IRCH, Aragats–751M, and Aerosol developed at the High–Mountain Geophysical Institute (HMGI).[25]

Measurement of condensation nuclei and ice crystals is of great importance for investigating the cloud aerosol. The Rich–100 (Cessna–206),[34] General Electric 112L (WP–3D),[30] Johnson–Williams (C–130),[31] UW–IPC (C–131A),[57] SALA–2 (YAK–40),[25] and Kristall (YAK–40)[58] counters are used for this purpose.

Water content is an important characteristic of the cloud physics. Several methods have been developed to measure it. They are thermoelectric,[59] optical,[60] gravimetric,[61] freezing,[62] radiometric,[41] and capillary[63] methods as well as the method based on the cloud droplet spectrum measurement.[62] However, the hot wire method based on measuring the heat required for the evaporation of the water being deposited on the wire is most widely used. This method is employed in the Johnson–Williams water–content gauge produced by the Cloud Technology Corporation (USA). This sensor is placed onboard almost all foreign AL's. The Sabreliner,[36] which uses the PMS–King gauge, is an exception. Though the Johnson–Williams gauge has low accuracy and sensitivity (0.2...6 g/m^3) it is simple, reliable, and serial. The DIVO–1, 1L, 3, and 3L water content gauges developed by I.V. Molokanov from the HMGT are also based on the hot wire method.[41] These gauges have a threshold sensitivity of 0.003 g/m^3 and an error of 10%. The CAO SEIV–3 water content and cloud water content gauges are also based on this method. These gauges are placed onboard several AL's of the Russian Commitee on Hydrology and Meteorology (RCHM).[4,25,50,58]

GAS ANALYSIS COMPLEXES

The aircraft investigation of the gas composition has long been in use. But this type of sensing has been intensively developed in the last 15–20 years in connection with the problems of air pollution, climate change due to the green–house effect, effects of the formation of ozone holes over the poles, etc. Therefore, the number of airborne complexes for gas analysis is not as large as, for example, for the investigation of cloud aerosol.

It can be seen from Table II that this type of devices is lacking onboard many AL's. From the available complexes, the LS–400, Mod. 8440, and RFM placed onboard the Cessna–206, Dacom and Beckman–865 onboard the Electra, 1003–AH and Dassibi onboard the WP–3D, Kok Inc. and Monitor Labs onboard the King Air,[65] FSRC CAO GKP–1 and 3–OP and GIAM–15 placed onboard the AN–30 aircraft of the Institute of Atmospheric Optics (IOA) can be mentioned. It follows from this list that the routine gas analysis is carried out onboard the AL's only for a few air components.

Another lead of airborne gas analysis is the application of the classic chemical methods with preliminary sampling and concentration of gases onboard the aircraft (indirect methods). The mass–spectrometric and gas–chromatographic methods and combined chromato–mass–spectrometric method[66] are most widely used. These methods are capable of determining the content of some gases whose concentration is several hundreds of atoms per litre.[67] Among the most important aspects of application of the indirect airborne methods are air sampling without distortions and concentrating of gases. The comprehensive reviews[68,69] are devoted to these problems. Usual sampling into the containers and sampling combined with particle concentrating, i.e., the absorption of impurities by a dissolvent and their cryogenic concentration or absorption on the solid sorbent, are used for air sampling. For the analysis of compound mixtures like the polycyclic aromatic hydrocarbons, they are preliminary deposited on the fine–porous filters or filtration, impregnation, and sorption are combined. Desorption appears to be an important factor of gas analysis by indirect methods. The elution, thermal desorption, vacuum desorption, vapor desorption, and solution are most often used. The extraction of impurities after their concentration, their desorption, and numerous operations of concentrate processing introduce the largest systematic error in the results of determining the gas concentration being about 2/3 of the total error.[70]

From the experimental methods which were tested onboard the aircraft we may point out the following: optical (spectroscopic) method, laser fluorescence, differential absorption method, and mass–spectrometric and electrochemical methods. According to Ref. 71, a sensitivity of 1 ppm for formaldehyde (λ = 239.7, 326.1, and 339 nm) was reached by the airborne optical method; the laser fluorescence was used for the routine monitoring of aldehydes in the band 320–345 nm, and a detection threshold of 10 ppb was attained; the differential absorption method was implemented for monitoring of NO, NO_2, and HNO_3 in the range 2–15 μm with a threshold of 1–2 ppb; the mass–spectrometry combined with the chemical ionization was capable of airborne detection of aldehydes at a level of several ppt; the best sensitivity of airborne electrochemical methods was 0.3–5 ppm with an error of ±5%.

However, in spite of the intensive development of the airborne gas–analysis methods, the most part of the data on the gas composition of air have thus far been obtained only by the indirect methods. It is confirmed by the results of the GTE/CITE–2 program on intercalibration of the gas–analysis instrumentation implemented by NASA onboard the Electra.[29] As part of this program, the best characteristics were reached by the indirect methods.

ACTINOMETRIC COMPLEXES

The instrumentation for measuring the net hemispherical upwelling and downwelling radiation fluxes is placed onboard the most part of foreign aircraft–laboratories. The Eppley stationary pyranometers and pyrheliometers of various models are used for this purpose. The PIR and Mod. 2 devices are placed onboard the Electra, C–130, and C–131A; the PSP and PIR devices are installed onboard the Sabreliner. They operate in the wavelengths ranges 0.2–3 μm and 4–50 μm. The King Air, on which the LI–COR device is installed, is the exception.

From the domestic aircraft–laboratories, only the FRS CAO AL is equipped by the actinometric instrumentation. Earlier such an instrumentation was installed onboard the MGO IL–18 AL.[72] However, the regular actinometric measurements were not carried out from onboard the domestic aircraft–laboratories.

RADIOMETRIC COMPLEXES

In addition to the radiometers, various spectrophotometers and microwave devices implementing the same measurement principle can be tentatively assigned to the radiometric instrumentation (Table III).

The radiometers, which are placed onboard the aircraft–laboratories, are intended to measure the radiative temperature of the underlying surface or of the upper boundary of clouds. Usually they operate in the 9–11 μm transparency window of the atmosphere. The radiometers of the Barnes type are used onboard the foreign AL's. For example, the PRT–5 and the scanning PRT–6 are used onboard the Electra, the Barnes 14–325 is used onboard the Sabreliner. Unfortunately, we could not find the information about the spectrophotometers and microwave devices used onboard the foreign AL's. The program of the Goddar Center of Space Flights (USA) published in Ref. 10 is the only exception. A large number of such devices should have been developed as part of this program. However, the results of its implementation are still unpublished.

The domestic AL's are better equipped with the devices of this type (see Table III). A part of these complexes is the experimental models, the other part is used for mapping the spectral characteristics of the ground and for measuring its radiative temperature. Table III does not include the airborne meteorological devices. They are the IKRA and TETA devices used by the Flight Research Centre of the Central Aerological Observatory (FRC CAO)[4] and IT–3 placed onboard the MGO IL–14.[6,50]

ELECTROMETRIC GAUGES

We failed to find the information about the AL's or individual devices, except the C–160 aircraft–laboratory (France) intended for investigation of the lightnings[75] in the foreign literature.

The domestic aircraft–laboratories use mainly the devices developed at the MGO such as electric field strength gauge and current gauge.[4]

On the whole, this type of airborne measurements has practically went out of use in the last few years.

OPTICAL COMPLEXES

These devices are being increasingly used in airborne sensing of the atmosphere. Thus, the unique data on the content of the minor gas components in the stratosphere in the region of the ozone hole[77,78] were obtained with the NCAR Fourier spectrometer and the NASA UV spectrophotometer[76] placed onboard the DC–8 and with the Eppley solar spectrophotometer and NCAR spectrophotometer placed onboard the Electra.[26–29]

The nephelometers are widely used onboard the foreign AL's, for example, the MR–1550 onboard the Cessna–206 and the Meteorol. Research Inc. Mod. 1591 onboard the WP–3D and Queen Air.

Such devices are almost out of use onboard the domestic AL's. Only the RP–73 indicator of cloud transparency used onboard the YAK–40 of the Ukrainian Scientific–Research Institute on Hydrology and Meteorology (USRIHM)[58] and of the Flight Scientific Research Centre of the Central Aerological Observatory (FSRC CAO).[4]

AIRBORNE LIDAR COMPLEXES

A lot of papers (see, for example, Refs. 15, and 79–82) are devoted to the problem of the application of laser sensing for investigating the atmosphere and underlying surface. Some of them concern the problems of airborne lidar sensing. However, the available information is insufficient to have an idea of the state of the art in this field. Only the review of I.V. Samokhvalov and V.S. Shamanaev[83] makes up largely for a deficiency in this direction. Table IV, which includes the information about the lidars which have been used previously or the standard lidars placed onboard the aircraft–laboratories for sensing the atmosphere and the underlying surface, is compiled from the data reported in this review taking into account more recent publications.

It can be seen from Table IV that the most part of the airborne lidars is intended for sensing of the atmospheric aerosols and clouds. Quite a large number of lidars were developed for solving the hydrographical problems. Among them are the detection of pollution of the water surface including the measurements of the oil film parameters, monitoring of the optical properties of the upper layers of the ocean and presence of hydrosol and plankton, and measuring the heights of the wind–driven sea waves. There are some lidars for sensing the meteorological parameters including air humidity. A start has been made on the development of the lidars for sensing the gas composition of air.

In our opinion, the data in Table IV testify that airborne laser sensing is coming from the experimental stage to the practical application not only to scientific investigations but also to the solution of the problems of the national economy.

AIRBORNE SYSTEMS OF DATA RECORDING

The performance of the aircraft–laboratories depends strongly on the degree of sophistication of the methods of data processing and accumulating. Depending on the way of solving the problem, all types of the recording systems can be divided into highly specialized and multipurpose. By the architecture the systems can be divided into individual and centralized, etc. Let us consider only the concrete types of their realization disregarding the peculiarities of the technology of construction of the recording systems.

The ARIS–III system which was placed onboard the Sabreliner and DC–5 Buffalo was described in Ref. 121. The input interface of this system includes 40 input analog channels (±5V), a 72–bit parallel input current instruction register, a channel for receiving the serial digital codes, and four inputs for receiving the signals from selsyns. The ARIS–III system is equipped with a transient interface for the communication with the navigation system and with the ADARS information–calculation complex. The data are recorded on a seven–channel magnetic–type units. The system of ground–based data processing is built around a basic IBM computer.

TABLE III. Specifications of the airborne radiometric and microwave complexes.

Aircraft type, organization, and reference	Application (name) of the instrument	Type or firm	Measurable characteristics	Wavelength or frequency	Angular beamwidth or aperture	Sensitivity, threshold, or measuring range	Spatial resolution	Off–nadir observation angle	Scanning	Comment
1	2	3	4	5	6	7	8	9	10	11
IL–18, IRE RAS, SPU "Vzlet", Russia, Ref. 23	Block of the nadir base radiometers	R–11	Characteristics of the underlying surface	11 cm	26°	0.4 K/s	2.7 km	0	–	
		R–21		21 cm	26°	0.4 K/s	2.7 km	0	–	
		R–80		8 mm	4°	0.5 K/s	0.4 km	0	–	
		R–135		1.35 cm	6°	0.5 K/s	0.6 km	0	–	
		R–225		2.25 cm	9°	0.1 K/s	0.9 km	0	–	
		R–27		27 cm	26°	0.4 K/s	2.7 km	0	–	
	Scanning radiometers	SR–80		8 mm	1.5°	0.5 K/s	0.12 km	–	–	
		SR–135		1.35 cm	2°	0.4 K/s	0.16 km	–	–	
		SR–225		2.25 cm	2°	0.4 K/s	0.16 km	–	–	
		Del'ta		–	–	–	–	– 40°	–	
		RP–08		8 mm	6°	0.1 K/s	0.6 km	+ 42°	–	
		RP–225		2.25 cm	9°	0.2 K/s	0.9 km	+ 42°	–	
		RSA11V22		10 cm	4×40°	–	20–25 m	45°	–	
	Radio altimeter	Greben'		2.25 cm	1.5°	–	0.1 m	0	–	
	Aerophotography	–		–	41°	–	7–10 m	0	–	
IL–14, LPI, MGO, St. Petersburg, Russia, Ref. 73	Super–high–frequency radiometric complex		Ground moisture	95 MHz	–	0.15 K/s	–	–	–	
				370 MHz	–	0.08 K/s	–	–	–	
IL–14, IAPA, Tartu, Estonia, Ref. 74	Programmable gauge of the scattering phase function	PII–1	Optical characteristics of the underlying surface	481(12.5) nm	3°	–	–	75°	With a step of 3° at a scanning rate of 120 steps/s	
				553(3.5) nm	3°	–	–	75°		
				667(22.7) nm	3°	–	–	75°		
				759(10) nm	3°	–	–	75°		
	Recording system	Elektronika–60								

TABLE III (continued).

1	2	3	4	5	6	7	8	9	10	11
AN–2 AUSRIAM, SPU "Selektsionnaya tekhnika," Russia, Ref. 9	Photometric complex	SKPA	Spectral brightness of plant canopy	0.40 μm 0.45 μm 0.50 μm 0.55 μm 0.60 μm 0.67 μm 0.70 μm 0.75 μm 0.78 μm 0.84 μm 0.90 μm 1.0 μm 1.05 μm 1.1 μm	23.5±0.5°	–	–	–	0.5 s in every channel	
	Recording system	D3–38		1.2 μm 1.25 μm						
IRE UAS, Ukraina, Ref. 16	Radiophysical complex including side–viewing radar and scanning radiometer	– –		3 cm 8 mm	– –	1.5 K 0.3 K	45×70 m 500×500 m	– –	– –	Vertical polarization (V) and horizontal polarization (H)
ISR RAS, Russia, Ref. 17	Radiophysical complex	Radiometer	Hydrophysical characteristics of the surface	0.3 cm 0.8 cm 0.8 cm 1.5 cm 1.5 cm	9° 9° 9° 9° 9°	0.25 K 0.1 K 0.2 K 0.15 K 0.2 K	– – – – –	0 0–80° 0–80° 0–80° 0–80°	– – – – –	V V H V H
		Two–channel radiometer, radiometer, radiometer–variometer, radiometer, radiometer, radiometer, and IR–radiometer		8 cm 18 cm 2 cm 0.8 cm 1.5 cm 0.3 cm 0.8 cm 1.35 cm 11 μm	15° 25° 6° 9° 9° 9° 15° 15° 8°	0.1 K 0.1 K 0.03 K 0.2 K 0.2 K 0.3 K 0.3 K 0.2 K 0.05 K	– – – – – – – – –	0 0 0 0 0 180° 180° 180° 0	– – – – – – – – –	V V V and H – – V V V –

TABLE III (continued).

1	2	3	4	5	6	7	8	9	10	11
AN–30, IAO SB RAS, Russia, Ref. 33	Radiometric complex	Spectrophotometer	Optical characteristics of the surface	440 nm 487 nm 551 nm 630 nm 670 nm 1060 nm 1221 nm 1620 nmn	0.4°	–	–	0–90°	20°/s	
		Radiometer	Radiative temperature	8.1 μm 9.1 μm 10.2 μm 12.1 μm 14.8 μm	1.0°	150–320 K	–	0–90°	20°/s	–
IL–18, MGO, Russia, Ref. 13	Microwave complex		Radiative temperature	0.8 cm	1.0°	2 K	–	+50°	–	H
				0.8 cm	1.2°	0.1 K	–	+30°	–	V and H
				1,35 cm	1.2°	1.0 K	–	+50°	–	H
				1.6 cm	1.6°	1.5 K	–	+50°	–	H
				1.9 cm	–	1.2 K	–	0	–	H
				2.1 cm	–	0.03 K	–	+45°	–	V
				2.45 cm	–	0.8 K	–	0	–	H
				3.2 cm	2.8°	0.2 K	–	+30°	–	V and H
				5.0 cm	–	0.1 K	–	30°	–	H
				5.0 cm	3.5°	0.8 K	–	0	–	V and H
				8.5 cm	6.1°	2.0 K	–	0	–	V and H
				11.5 cm	–	0.1 K	–	20°	–	V and H
				14.0 cm	–	0.1 K	–	20°	–	V and H
				18.0 cm	–	0.1 K	–	20°	–	V and H
				21.0 cm	–	0.5 K	–	0	–	H
				35.0 cm	–	0.5 K	–	0	–	H

TABLE IV. Basic specifications of airborne lidars.

Lidar	Application	Laser	λ, μm	f, Hz	Pulse width, ns	Receiving optics or its diameter, mm	Beam divergence, mrad	Power or energy	Aircraft–laboratory	Reference	Comment
1	2	3	4	5	6	7	8	9	10	11	12
Mark–5 (Stanford Inst.)	Aerosol	Nd–glass	1.060	20.0	12	150	0.3	50 mW	WC–130B	84	
LR–2	Clouds	Ruby	–	–	–	MTO–1000	–	–	IL–18	85	Polarization
LR–3 (CAO)	Clouds	Garnet	0.532	–	15	MTO–1000	0.3	10 mJ			
(NASA)	Aerosol	Phodamine RBL	0.585	–	500	200	–	0.4 J	Electra	86	
	Aerosol	Ruby	0.6943	0.1	20	380	–	1 J	–	87	
(NASA)	Clouds	Garnet	0.532	5.0	8	180	1.0	50 mJ	–	88	Parallel and perpen-dicular polarizations
ALPHA–1	Aerosol	Garnet	1.06; 0.532	10.0	15	350	2.0	100 and 20 mJ	Queen Air	88 and 90	
ALARM	Aerosol and gases	CO_2	10.60	–	–	–	–	–			
(NASA)	Aerosol	Ruby	0.6943	1.0	30	360	1.0	1 J	P–3A	91	Operation in the zenith
ALEX–F	Aerosol	NT–672	0.532; 1.06	10.0	–	350	2.0	120 and 400 mJ	–	92	
Spacelab	Aerosol	Glass	1.06	–	10	450	–	0.1 J	–	93	
(NASA)	Aerosol and O_3	Iron Iodide	0.286; 0.300; 0.600	10.0	–	350	–	0.35 J		94	
Svetozar	Clouds	Ruby	–	0.1	–	100	1.0	–	IL–14	95	Linear polarization
Svetozar–2	Aerosol	Glass	–	0.3	30	200	–	0.15 J	IL–18DORR	1.0	Linear polarization
Svetozar–3		Ruby	0.532	–	15	3×100	–	0.01 J	AN–30	1.0	Linear or circular polarization
IAO RAS	Clouds	–	0.530	–	15	MTO–500	7.0	–	–	96	
L–1M	Aerosol	–	0.530	0.1	30	210	1.3	0.5 J	–	97	
IP Beloruss. AS		–	1.060			300	–	0.06 J			
IR–lidar (NCAR)	Aerosol	CO_2 (two models)	–	–	130	300	–	0.3 and 0.21 J	King Air	98	

TABLE IV (continued).

1	2	3	4	5	6	7	8	9	10	11	12
AOL (NASA)	Oceanography	Neon	0.5401	400	7	300; 300		2 kW	C–54	99	Scanning
Modification of the AOL (NASA)	Oceanography	N_2; Nd:YAG; CO_2	0.337; 0.532; 9.500	200; 6.25; 2	10; 15; 100	180	2.6; 0.4–4.0; 2.0	0.3 J	P–3A	100	
WRELADS–2 (Australia)	Oceanography	Garnet	1.064; 0.532	168 or 84	7 and 5	180	–	5 mJ	F–27	101	
CCRS (Canada)	Oceanography	NT–462	0.532; 1.064	10	5	–	–	10 and 15 mW	Twin Otter	102	
Chaika (IGP RAS)	Oceanography	Garnet with ampl.	0.532	10	–	300	–	50–100 mJ	AN–30	103	
(Canada)	Oceanography	N_2; Ne	0.3371; 0.5401	1–100	9 and 3	–	13 and 26	140 and 20 kW	–	104	
	Oceanography	N_2	–	–	3	–	1.0	1 mJ	–	105	
(Italy)	Oceanography	YAG (third harm.)	0.355	–	2	–	0.1	50 mJ	–	106	
(FRG)	Oceanography	Excimer Dye	0.308; 0.450; 0.533	2	6	400	–	10 and 1 mW	–	107	
(FRG)	Oceanography	Dye	–	–	3000	200	–	1 J	–	108	
DIAL (NASA)	Aerosol and O_3	–	–	–	–	–	–	–	Electra	109	
(Japan) Cooperation	Aerosol	CO_2 (two lasers)	9.0–11.0	–	–	300	–	0.3 J	B–727	110	
DIAL (NASA)	O_3, NH_3, C_2H_4, P, T, and H_2O	–	0.727; 0.940	10	–	1250	–	0.5 J	ER–2	111	
(MEPI)	CH_4 and pipelines	CO_2	0.9217; 0.9228	–	–	–	–	–	–	112	
(NCAR)	Wind	CO_2	10.800	–	–	–	–	–	CV–990	113	Heterodyne
(Colorado Univ.)	Aerosol and gases	Nd:YAG	1.064	2	–	14 in.	2.0	0.1 J	C–131A	114	
DIAL (NASA)	P and gravitational waves	Alexandrite	0.725–0.790	10	100	400	–	0.1–0.15 J	Electra	115	
(NASA)	Aerosol	Nd:YAG+CH cell	1.064; 1,540	–	–	400	–	–	DC–8	116	Zenith, nadir
(France)	Aerosol	Nd:YAG	1.064; 0.532	10	10	300		130 and 80 mJ	F–27	117	Linear polarization
(FRG)	Aerosol and H_2O	Nd:YAG	0.720	10	–	400	30	–	Falcon	118	
(MGO)	Aerosol	–	0.690	–	30	–	–	–	IL–18; YAK–40	119	
LATAS (Alabama Univ.)	Aerosol and wind	CO_2	10.590	–	–	150	–	1.5 W	C–131	120	Linear polarization

In addition, the universal ADARS system[122] of data collection and recording is placed onboard the same AL's. It is intended for data processing by the ARIS–III system with the additional calculation of the pilot, navigation, and meteorological data, their indication and preparation to the transmission by telemetry through a channel built around the ROLM–1601 computer. The serial polling time of the ARIS–III system is 2 s. In this case 32 values of the measurable parameters enter the ADARS system. The operator can quickly input the results of the visual observations for their subsequent storage on the magnetic tape by means of the video terminal.

The EDMS recording system[123] was placed onboard the L–188 Electra aircraft–laboratory. It has the bus–module architecture. The system is built around the two computers with 16 kbyte random–access memory in each. The first is used for data collecting and processing, the second is used for preparing the output data arrays and controlling the external devices. The EDMS system has a 50–channel analog–digital converter, five–channel converter of the serial code into the parallel one, ten–channel frequency–code converter, and eight–channel 2–byte parallel buffer with address retrieval for the communication with the sources of the data. The input and output interfaces are used for communication with the OMEGA inertial navigation system.

The CADS multipurpose information–calculation complex[124] is placed onboard the King Air AL's. The four–processor system is assembled on the common bus in the Intel Multibas standard. Two magnetic tape units and LTN–76 inertial navigation system as well as up to 16 sensors with the analog outputs (0–10V) and four series channels with a pulse repetition frequency of 100 Hz are connected to two processors. The airborne Doppler radar and four Knollenberg's counters are connected to the second pair of the processors. The CADS system has three Intel–8086 CPV central processors operating in parallel. One of them, main processor, performs data collecting and processing, displaying the results on a screen, and software testing of the units of the complex. The second processor is intended for radar data processing and composition and display of the combined images. The third processor calculates the cloud particle size spectrum and forms its two–dimensional display on a screen. The maximum bit rate summed over all channels is 92000 bytes/s for the CADS system.

The recording system of the C–131A AL of Washington University was briefly described in Refs. 125 and 126. It is built around the IBM–PC–2 and has 16 analog inputs (+5V) and 32 discrete TTL channels. The sensors are polled with a frequency of 10 Hz. The data magnetic–type unit has a memory capacity of 67 Mbyte sufficient for 18.2 hours of flight. The system is equipped with the HP2671G thermal printer capable of printing 120 text characters per second and 90 graphic characters per second.

The recording systems placed onboard the domestic aircraft–laboratoties are the most critical elements of the airborne measuring complexes. Thus, the K series optical recorders[58] were recently used onboard the USRIHM YAK–40, the Iskra–1256 computer was used onboard the MGO IL–14 (see Ref. 6), and the D3–28 computer was used onboard the IL–14 of the Institute of Astrophysics and Atmospheric Physics (IAAP) (Estonia).[74] Therefore, the BARS system[5] developed at CAO can be considered progressive. This system is built around a more modern computer. And only most recently the IBM series computers[33] have come into use onboard the domestic AL's.

In conclusion, summing up the results of our paper on the whole, we note that it is doubtful weather it is possible to analyze all the aspects of airborne sensing even in a very voluminous paper. In addition, the problem becomes more complicated due to the fact that many aspects of this manifold problem are covered in the official reports, which have a small circulation, and, as a rule, are little known to the wide scientific community. Therefore, this review is an attempt of maximum encompassing of all geophysical applications of the aircraft–laboratories with subsequent distinguishing the most characteristic details. We hope that this review will be useful for those who want to know the problem as a whole or to determine their own position in relation to such investigations.

REFERENCES

1. V.A. Zaitsev and A.A. Ledokhovich, *Instrumentation and Procedure for Airborne Investigation of Clouds* (Gidrometeozdat, Leningrad, 1960), 175 pp.
2. V.A. Zaitsev and A.A. Ledokhovich, *Instrumentation for Investigation of Fogs and Clouds and Measuring Air Humidity* (Gidrometeoizdat, Leningrad, 1970), 255 pp.
3. Yu.V. Mel'nichuk, A.N. Nevzorov, and G.N. Shur, Meteorol. Gidrolog., No. 2, 112–119 (1980).
4. V.K. Babarykin, V.F. Grakovich, L.F. Grigor'ev, et al., *Instrumentation of Meteorological Aircraft–Laboratories and Data Processing Techniques*, All–Union Scientific–Research Institute of Hydrological and Meteorological Information – World Information Center, Obninsk (1981), No. 1, 48 pp.
5. A.V. Litinetskii, *"Development of airborne instrumentation for temperature and wind velocity measurements in real time,"* Candidate's Dissertation in Technical Sciences, Central Aerological Observatory, Dolgoprudnyi (1989), 245 pp.
6. A.A. Sin'kevich, *"Development of the airborne meteorological instrumental complex, procedure for their application, and some results of experimental investigations of clouds,"* Author's Abstract of Doct. Thesis. in Technical Sciences, Main Geophysical Observatory, St. Petersburg (1992), 27 pp.
7. M.W. Douglas, Bull. Amer. Meteorol. Soc. **71**, 1746–1757 (1990).
8. E.E. Meleshko, in: *Spectrophotometric Research of Natural Earth's Covers* (Nauka, Leningrad, 1978), pp. 34–38.
9. Yu.E. Samsonov, M.I. Shveidel', A.P. Kul'chitskii, et al., Tr. Vses. Nauchno–Issled. Inst. S.–kh. Mashinostr., No. 14, 92–99 (1984).
10. R.J. Serafin, G. Szejwach, and B.B. Phillips, J. Geophys. Res. **C91**, No. 2, 2510–2516 (1986).
11. V.V. Mikhailov and V.P. Voitov, Atmospheric Physics Problems, No. 7, 175–181 (1969).
12. A.N. Volkov, D.M. Kabanov, S.M. Sakerin, and S.A. Turchinovich, in: *Instrumentation for Remote Sensing of Atmospheric Parameters* (Tomsk Affiliate of the Siberian Branch of the Academy of Sciences of the USSR, Tomsk, 1987), pp. 71–81.
13. K.Ya. Kondrat'ev, V.V. Melent'ev, and V.A. Nazarkin, *Spaceborne Remote Detection of Water Areas and Collectors* (Gidrometeoizdat, St.Petersburg, 1992), 248 pp.
14. Sh.D. Fridman, E.V. Kolomeets, A.N. Pegoev, et al., *Monitoring of Water Capacity of Snow, Soils, and Glaciers by Natural Penetrating Radiations* (Gidrometeoizdat, Leningrad, 1990), 264 pp.

15. V.M. Orlov, I.V. Samokhvalov, M.L. Belov, et al., *Remote Monitoring of the Upper Layer of the Ocean* (Nauka, Novosibirsk, 1991), 149 pp.
16. A.S. Kirilenko, V.V. Kryzhanovskii, Yu.A. Kuleshov, et al., Preprint No. 321, Institute of Radio Electronics of the Ukrainian Academy of Sciences, Khar'kov (1986), 39 pp.
17. V.S. Etkin, B.E. Aleksin, V.M. Aniskovich, et al., Preprint No. 1279, Institute of Space Research of the Academy of Sciences of the USSR, Moscow (1987), 43 pp.
18. V.N. Barakhtin and V.K. Kotel'nikov, Proceedings of the West Siberian Regional Scientific–Research Institute on Hydrology and Meteorology, No. 24, 12–17 (1976).
19. G.S. Gorin, M.D. Suprun, V.V. Drozhzhin, and S.A. Koshurnikov, Proceedings of the State Scientific–Research Center for Exploration of Natural Resources, No. 38, 123–126 (1989).
20. L.A. Mirmovich, K.Ya. Orlov, and V.A. Parkhimovich, Tr. Ukr. Nauchno–Issled. Gidrometeorol. Inst., No. 170, 123–126 (1979).
21. V.P. Belyaev and V.K. Dmitriev, Tr. Tsentr. Aerol. Obs., No. 128, 93–101 (1977).
22. S.A. Alekseev, Zarubezhnoe Voennoe Obozrenie, No. 12, 59–65 (1983).
23. *Airborne Complex for Exploration of Natural Resources and Examination of Extraordinary and Ecological Situations.* Prospectus of Moscow Branch of the Space Aero–Geological Expedition (1991), 16 pp.
24. O.B. Vasil'ev, *"Spectral short–wave radiation fluxes and brightness in the atmosphere,"* Doct. Thesis in Phys.–Math. Sci., State University, Leningrad (1987), 387 pp.
25. G.B. Myakon'kii, M.I. Tlisov, and L.D. Fedchenko, in: *Artificial Modification of Hail Processes and Outlook for the Improvement of Ice–Forming Reagents in Practice of Artificial Modification* (Gidrometeoizdat, Leningrad, 1991), pp. 77–84.
26. R.L. Folt, Atmos. Technol. **3**, No. 1, 16–17 (1973).
27.S. Nicholls, W. Shaw, and T. Hauf, J. Clim. and Appl. Meteorol. **22**, No. 9, 1637–1648 (1983).
28. M. Garstang, E. Browell, G. Sachse, et al., J. Geophys. Res. **D93**, No. 2, 1528–1550 (1988).
29. J.M. Hoell, D.L. Albulton, G.L. Gregory, et al., J. Geophys. Res. **D95**, No. 7, 10047–10054 (1990).
30. R.C. Schnell, T.B. Watson, and B.A. Bodhaine, J. Atmos. Chem. **9**, Nos. 1–3, 3–16 (1989).
31. C.J. Readings, Meteorol. Mag. **114**, No. 1352, 66–77 (1985).
32. A. Grant and S. Zank, Contrib. Atmos. Phys. **59**, No. 1, 185–194 (1986).
33. V.E. Zuev, B.D. Belan, D.M. Kabanov, et al., Atm. Oceanic Opt. **5**, No. 10, 706–711 (1992).
34. *Aircraft Instrumentation for Cloud Physics Research and Weather Modification Programs,* Report WMO No. 7, Geneva, 1978, 62 pp.
35. P.J. Kennedy and D. Frey, ALPEX Aircraft Data Documentation NCAR, Boulder, 1983, 88 pp.
36. M. Tjernstrom and C.A. Friehe, J. Atmos. and Ocean Technol. **8**, No. 1, 19–40 (1991).
37. E. Haering, AIAA Pap., No. 0230, 1–24 (1990).
38. V.Yu. Polyakov, ed., *Airborne Navigation Systems* (Voenizdat, Moscow, 1973), 416 pp.
39. V.G. Vorob'ev, *Airborne Instruments and Measuring Systems* (Transport, Moscow, 1982), 392 pp.
40. D.L. Blumenthal, J.A. Ogren, and J.A. Anderson, Atmos. Environ. **12**, 613–620 (1978).
41. M.T. Abshaev and Kh.M. Baisiev, Proceedings of the All–Union Scientific–Research Institute of Hydrological and Meteorological Information–World Information Center, No. 2, 1–54 (1988).
42. D.A. Braslavskii, S.S. Logunov, and D.S. Pel'kor, *Airborne Instruments and Automatic Devices* (Mashinostroenie, Moscow, 1978), 482 pp.
43. Th. Hauf, Meteorol. Rundsch. **37**, No. 5, 163–176 (1984).
44. D.E. Ziegler and J. McCarthy, Bull. Amer. Meteorol. Soc. **62**, No. 3, 403–411 (1981).
45. T. Toya, F. Kimura, and N. Murayama, J. Meteorol. Soc. Jap. **64**, No. 3, 431–442 (1986).
46. D.L. Blumenthal, J.A. Ogren, and J.A. Anderson, Atmos. Environ. **12**, 613–620 (1978).
47. T.J. Conway, W.E. Raatz, and R.H. Gammon, Atmos. Environ. **19**, No. 12, 2195–2201 (1985).
48. D. Paffrath and W. Peters, in: *VI Congr. mond qualite air*, Paris (1983), pp.133–136.
49. M. Koldovski and M. Prokop, Problems of the Background Monitoring of the State of Environment, No. 4, 234–236 (1986).
50. V.V. Zvonarev, V.S. Lyadov, Yu.F. Ponomarev, et al., Proceedings of the Main Geophysical Observatory, No. 497, 51–62 (1986).
51. A.M. Baranov and S.V. Solonin, *Aviation Meteorology* (Gidrometeoizdat, Leningrad, 1981), 384 pp.
52. D.A. Braslavskii, *Instruments and Sensors of Aircrafts* (Mashinostroenie, Moscow, 1970), 392 pp.
53. D.H. Lenshow, NCAR Techn. Note EDD–74, Boulder, 1972, 42 pp.
54. D.N. Axford, J. Appl. Meteorol. **27**, No. 4, 488–496 (1988).
55. I.S. Lechner, G.W. Fisher, H.R. Larsen, et al., J. Geophys. Res. **D94**, No. 12, 14893–14903 (1989).
56. P. Gorner and J.F. Fabries, Inst. nat. rech. secur., No. 140, 595–626 (1990).
57. Ch.A. Brock, L.F. Radke, J.H. Lyons, and P.V. Hobbs, J. Atmos. Chem. **9**, Nos. 1–3, 129–148 (1989).
58. F.Ya. Voit, L.A. Mirmovich, and A.I. Furman, Proceedings of the Ukrainian Scientific–Research Institute on Hydrology and Meteorology, No. 212, 112–119 (1987).
59. W.D. King, D.A. Parkin, and R.H. Handsworth, J. Appl. Meterol. **17**, No. 12, 1780–1785 (1978).
60. R.G. Knollenberg, J. Appl. Meteorol. **11,** No. 3, 501–508 (1971).
61. E.E. Kornienko and L.A. Mirmovich, Proceedings of the Ukrainian Scientific–Research Institute on Hydrology and Meteorology, No. 74, 130–133 (1968).
62. R.G. Knollenberg, in: *Clouds, Their Formation, Optical Properties, and Effects* (Academic Press, New York, 1988), pp. 15–89.

63. J. Warner and T.O. Newhman, Quart. J. Roy. Meteorol. Soc. **78**, 48–52 (1952).
64. F.J. Merceret and T.L. Schricker, J. Appl. Meteorol. **14**, No. 2, 319–326 (1975).
65. J.F. Boatman, D.L. Wellman, C.C. Valin, et al., J. Geophys. Res. **D94**, No. 4, 5081–5093 (1989).
66. I.A. Revel'skii, Yu.S. Yashin, V.E. Milli, et al., Uch. Zap. Tartu Gos. Univ., No. 844, 156–170 (1989).
67. Yu.S. Drugov, Zavod. Lab. **54**, No. 7, 3–13 (1988).
68. R. Jaenicke and J. Hahn, CODATA Bulletin **21**, No. 1, 1–111 (1989).
69. Yu.S. Drugov and V.D. Yagodovskii, Prob. Analit. Khim., No. 10, 113–143 (1990).
70. W. Jennings and A. Rapp, *Preparation of Samples for Gas Chromatography Analysis* [Russian translation] (Mir, Moscow, 1986), 166 pp.
71. R. Otson and Ph. Fellin, Sci. Total Environ. **77**, Nos. 2–3, 95–131 (1988).
72. K.Ya. Kondrat'ev and N.E. Ter–Markaryants, Proceedings of the Main Geophysical Observatory, No. 366 (1975), 98 pp.
73. Scientific Research Report No. 01830081464, Polytechnic Institute, Leningrad, 1985, 146 pp.
74. Scientific Research Report No. 056351, Institute of Astrophysics and Atmospheric Physics of the Estonian Academy of Sciences, 1989, 54 pp.
75. M. Friedlander, Rev. Palais Decouv. **15**, No. 143, 36–38 (1986).
76. M.T. Coffey, W.G. Mankin, and A. Goldman, J. Geophys. Res. **D94**, No. 14, 16597–16613 (1989).
77. A.F. Tuck, R.T. Watson, E.P. Condon, et al., J. Geophys. Res. **D94**, No. 9, 11181–11222 (1989).
78. R.H. Kerr, Science **243**, No. 4894, 1007–1008 (1989).
79. V.E. Zuev, *Laser–Meteorologist* (Gidrometeoizdat, Leningrad, 1974), 178 pp.
80. V.E. Zuev, *Propagation of Laser Radiation through the Atmosphere* (Radio i Svyaz', Moscow, 1981), 288 pp.
81. V.E. Zuev, B.V. Kaul', I.V. Samokhvalov, et al., *Laser Sensing of Industrial Aerosols* (Nauka, Novosibirsk, 1986), 186 pp.
82. V.M. Zakharov, O.K. Kostko, and S.S. Khmelevtsov, *Lidars and Climate Research* (Gidrometeoizdat, Leningrad, 1990), 320 pp.
83. I.V. Samokhvalov and V.S. Shamanaev, VINITI, No. 2403–B88, Moscow, 1988, 38 pp.
84. E.E. Uthe and W.B. Jonson, Final Report AT (04–03)–115SRY Project No. 7929, Menlo Park, 1971, 78 pp.
85. V.M. Zakharov, O.K. Kostko, V.M. Orlov et al., Proceedings of the Central Aerological Observatory, No. 102, 144–149 (1971).
86. G.W. Gams, E.M. Patterson, and C.M. Wyman, Opt. and Quant. Electr. **7**, 187–191 (1975).
87. J.A. Eckert, J.L. McElroy, D.H. Bundy, et al., in: *Abstracts of Reports at the Int. Conf. Environ. Sens. and Asses.*, Las Vegas; New York (1976), pp. 10.3/1–10.3/4.
88. J.D. Spinhirne, M.J. Hansen, and L.O. Candill, Appl. Opt. **21**, No. 9, 1564–1571 (1982).
89. E.E. Uthe, W. Viezee, B.M. Morley, and J.K.S. Ching, Bull. Amer. Meteorol. Soc. **66**, No. 10, 1255–1262 (1985).
90. E.E. Uthe, in: *Abstracts of Reports at the Int. Geosc. and Remote Sens. Symp. (IGARSS'83): Remote Sens.* (1983), pp. 4.5/1–4.6/6.
91. W.H. Fuller, D.M. Robinson, and B.R. Rouse, in: *Abstract of Reports at the Ninth Int. Laser Radar Conf. Laser Atmos. Stud.*, Munich (1979), pp. 153–154.
92. P. Morl, F. Reinhardt, and W. Renger, DFVLR–Nachr, No. 27, 26–28 (1979).
93. Ch. Werner, F. Bachstein, S. Dietr, et al., Rev. Sci. Instrum. **49**, No. 7, 974–981 (1978).
94. E.V. Browill, S.T. Shipley, A.F. Carter, and C.F. Butler, NASA Conf. Publ., No. 2228, 60–63 (1982).
95. A.I. Abramochkin, V.V. Zanin, I.E. Penner et al., Atm. Opt. **1**, No. 2, 92–96 (1988).
96. A.K. Gorodetskii, Yu.A. Gol'din, N.A. Knyazev, et al., Izv. Akad. Nauk SSSR, Fiz. Atmos. Okeana **16**, No. 8, 867–869 (1980).
97. A.P. Ivanov, A.P. Chaikovskii, K.N. Dyatlov, et al., J. Prikl. Spektrosk. **26**, No. 6, 1044–1052 (1987).
98. R.L. Schwiesow and P.A. Lightsey, NASA Conf. Publ., No. 2431, 273–275 (1986).
99. F.E. Hoge, R.N. Swift, and E.B. Friederick, Appl. Opt. **19**, No. 6, 871–883 (1980).
100. Z.L. Bufton, F.E. Hoge, and R.N. Swift, Appl. Opt. **22**, No. 17, 2603–2618 (1983).
101. M.F. Penny, R.H. Abbot, and D.M. Phillips, Appl. Opt. **25**, No. 13, 2046–2058 (1986).
102. D.E. Reid, W.S. Gesing, B.N. William, and J.R. Gibson, IEEE, No. 5, 751–760 (1983).
103. A.G. Abroskin, F.V. Bunkin, D.V. Vlasov, et al., Proceedings of the Institute of General Physics of the Academy of Sciences of the USSR (1986), Vol. 1, pp. 23–29.
104. M. Bristow, in: *Abstracts of Reports at the Canadian Remote Sens. Society Aerospace Electron. Symp.,* Halifax (1975), pp. 148–150.
105. R.A. O'Neil, L. Buja–Bijnas, and D.M. Raciner, Appl. Opt. **19**, No. 6, 863–870 (1980).
106. A. Ferrario, P.L. Pizzolati, and E. Zanzottera, NASA Conf. Publ., No. 2431, 146–147 (1986).
107. D. Diebel–Longhorn, K.P.Gunther, T.Hengstermann et al., in: *Abstracts of Reports at the Int. Congr. Laser–85*, Munchen (1985), pp. 644–647.
108. U. Gehlhaar and J. Luther, in: *Abstracts of Reports at the Laser–79 Opto–Electron Conf.,* Munich (1979), pp. 514–519.
109. E.V. Browell, G.L. Gregory, R.C. Harries, and V.W.J. Kirchhoff, J. Geophys. Res. **D93**, No. 2, 1431–1451 (1988).
110. T. Itabe, K. Asai, M. Jchiru et al., Appl. Opt. **28**, No. 5, 931–934 (1989).

111. E.V. Browell, NASA Conf. Publ., No. 2450, 60–83 (1987).
112. V.V. Berezovskii, A.L. Gandurin, E.A. Igumnov, et al., Kvant. Elektron. **14**, No. 9, 1917–1919 (1987).
113. R.W. Lee, *Abstracts of Reports at the 21st Conf. Radar Meteorol.*, Boston (1983), pp. 655–657.
114. L.F. Radke, Ch.A. Brock, J.H. Lyons, and P.V. Hobbs, Atmos. Environ. **23**, No. 11, 2417–2430 (1989).
115. C.L. Korb, G.K. Schwemmer, D.O. Starr, et al., in: *Abstracts of Reports at the Fifteenth International Laser Radar Conference*, Tomsk (1990), Vol. 1, pp. 30–33.
116. J.D. Spinhirne, J.L. Bufton, J.F. Gavanaugh, and S. Chudanami, ibid., pp. 34–35.
117. J.Pelon, P.Flamant, and M.Meissonier, ibid., pp. 36–39.
118. G. Ehret and W. Renger, ibid., pp. 67–69.
119. A.D. Egorov, P.P. Boitson, A.A. Sinkevich, et al., ibid., p. 382.
120. D.A. Bowdle, J. Rothermel, J.M. Vaughan, et al., J. Geophys. Res. **D96**, No. 3, 5327–5335 (1991).
121. W. Glaser, Atmos. Technol. **3**, No. 3, 61–65 (1973).
122. J.B. Gramp, ibid, pp. 67–69.
123. N.D. Kelley, ibid., pp. 21–24.
124. P.R. Lawson and D.S. Treddenick, in: *Abstracts of Reports at the Fifth Symp. Meteorol. Obser. and Inst.*, Toronto (19830), pp. 283–285.
125. H.E. Terry and L.F. Radke, US Antarct. J. **23**, No. 5, 182–183 (1988).
126. Ch.A.Brock, L.F.Radke, J.H.Lyons, and P.V.Hobbs, J. Atmos. Chem. **9**, Nos. 1–3, 129–148 (1989).