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Airborne laser scanning: existing systems and firms and other resources

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Abstract

This article gives an overview of resources on airborne laser scanning (ALS). The main emphasis is on existing systems and firms, especially commercial ones. Through a very time-consuming search and with the help of numerous persons from firms, organisations and other colleagues, a quite complete survey of existing commercial systems, including detailed system parameters, has been compiled. This survey is by far the most complete and up-to-date information available today on commercial ALS. Additional data on contact information, links and, in some cases, a short background is given for firms involved in ALS (manufacturers, service providers, owners). A summary of other non-commercial and research systems, mainly of NASA, and respective links is presented. Finally, some other useful WEB links are given. The developments in ALS have been very rapid the last 1–2 years. This overview reflects these developments and describes rather completely the current situation, thus, being useful for all persons involved in ALS one way or another.

Keywords: airborne laser scanning; airborne laser scanners (technical specifications); airborne laser scanners (commercial firms)

1. Introduction

In 1996, there was only one company selling commercial ALS systems and the service providers could be counted on the fingers of one hand. Today, there are several manufacturers of complete systems or major ALS components, while the number of firms providing services have jumped to ca. 40 worldwide. ALS is literally taking off, although still in a development and consolidation stage.

2. Major components of an ALS system

The major components of an ALS (excluding profilers) include:

— a laser range finder (LRF): it includes the laser, transmitting and receiving optics, the signal detector, amplifier, time counter and necessary electronic components;

— computer, operating system and software for control of the on-line data acquisition;

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— storage media for laser, GPS, INS, scanner and possibly image data;
— a scanner;
— GPS and (excluding cases where attitude is estimated by multiple GPS antennas on the aircraft) an attitude measurement system (the term INS, although not precise, will be used in the sequel);
— platform and mounting of the system components;
— ground reference GPS station(s);
— software for mission planning, and various stages of postprocessing;
— GPS for navigation, possibly including radio links or antennas for receipt of real-time corrections;
— optionally, other sensors, especially video and digital CCD-cameras, photogrammetric aerial cameras, other sensors (thermal, multispectral line CCDs, etc.);
— optionally, temperature and humidity control.

From a system integration point of view, the first three components can be purchased using OTS components, sometimes including a scanner. With respect to GPS/INS, there is a clear tendency towards the products of Applanix, a firm that offers integrated hardware and software solutions for different accuracy levels. Platform, ground reference GPS stations, and, in some cases, simultaneous use of other sensors are mainly concerns of the firm using the ALS system. Last but not least, software for postprocessing is usually developed either by service providers (not manufacturers), users or researchers. Calibration (static and in-flight) and modelling of systematic errors are not mentioned here since they should be obvious, although unfortunately, in many cases, they are not treated with the proper care.

An important trend is towards programmability/selectivity of various parameters in order to allow more flexibility and adaptation to the different application requirements. Apart from flying speed and height, which can obviously vary, the following parameters are variable in one or the other system: scan angle, pulse rate, scan rate (often inverse proportionally related to scan angle), beam divergence, recording of first and/or last or multiple echoes per pulse, scanning pattern, and INS frequency. Other parameters which depend on the previous ones, like across and along track point spacing, swath width, point density and covered area/h can also vary. It should be noted here, that the selection of these parameters is not totally free, as there are operational restrictions, like laser power, storage capacity, etc.

Other tendencies include: higher flying height, higher pulse rate, recording of intensity and/or more than one echo per pulse, installation on multiple platforms, tighter integration of cameras and with higher resolution, wider selection of GPS receivers and inertial measurement units (IMU), smaller and lighter systems or components with less power requirements.

The laser wavelength is often in the range of 1040–1060 nm (and for bathymetric lasers also 532 nm), while a few systems have a wavelength of ca. 900 or 1550 nm. The only exception is the ScaLARS system which uses 810 nm wavelength and a continuous-wave laser (all others are pulsed).

The cost of a complete airborne system is ca. 700–1300 K USD (software and additional sensors like cameras may cost extra).

3. Summary of major technical parameters

Due to the length of Table 5 in Appendix A, minimum, maximum and typical values for some major technical parameters are summarised below to allow an easier overview (Table 1).

4. Manufacturers

Optech is the first commercial ALS manufacturer, at least in our field. Apart from, currently three, ALS models for topographic applications, it manufactured or provided components for three current bathymetric lasers (Larsen 500, SHOALS, HawkEye) and produces a number of systems for close-range applications. In 1997, Saab Survey Systems was added to the list with their TopEye system, while Saab Dynamics was already previously involved in bathymetric lasers (HawkEye). In 1998, Azimuth Corp., a company that had provided for over 10 years LRFs as components of ALS systems, started offering an almost complete surveying system, which in between has been or is planned to be sold to various firms in

Table 1
Overview of major technical parameters of ALS systems (excluding profilers and bathymetric lasers)

	Minimum value	Maximum value	Typical values
Scan angle (°)	14	75	20–40
Pulse rate (kHz)	5	83	5–15
Scan rate (Hz)	20	630	25–40
Flying height (h)(m)	20	6100	200–300 (H), 500–1000 (A)[a]
GPS frequency (Hz)	1	10	1–2
INS frequency (Hz)	40	200	50
Beam divergence (mrad)	0.05	4	0.3–2
Swath width (m)	0.25 h	1.5 h	0.35–0.7 h
Across-track spacing (m)	0.1	ca. 10	0.5–2
Along-track spacing (m)	0.06	ca. 10	0.3–1
Angle precision (roll, pitch/heading) (°)	0.004/0.008	0.05/0.08, 0.5/0.2[b]	0.02–0.04/0.03–0.05
Range accuracy (cm)	2	30	5–15
Height accuracy (cm)	10	60	15–20
Planimetric accuracy (m)	0.1	3	0.3–1

[a] H = helicopter, A = airplane.
[b] For systems with no true INS, using 3–4 GPS antennas for attitude determination.

USA. Nortech Geomatics has recently started selling ALS based on their ATLAS-VL and -SL systems. TopoSys plans to sell its TopoSys II system starting from end of 1999. RIEGL, mainly involved in close-range applications, also offers laser scanners for low-altitude platforms. NEC provides ALS components which have been used in three systems in Japan (details are not fully known but it seems that at least the LRF is provided).

Although not strictly manufacturers, some service providers build their own systems by integrating commercial components. This process has been supported by the increasing availability of commercial components, especially LRFs, scanners and GPS/INS systems. The major bottlenecks in putting-up a functioning system are the integration of these components and the development of software for control, synchronisation and especially intelligent and according to the application-at-hand postprocessing of the data.

5. Service providers

In 1996, service providers could be counted on the fingers of one hand. Currently, there are 26 firms providing services with laser systems that they, or their affiliates, own, 10 firms leasing systems from others, four firms providing services for bathymetry/hydrography, and five owners of systems, most of them only for their internal use (see Table 2). Finally, consulting firms are slowly emerging (currently two). Due to the high system (and platform) costs and since the market is still in a developing stage and no company can get a big enough share of the market in order to keep its ALS system busy, there are often cooperations between companies and joint ventures, sharing of systems, leasing, etc. (an extreme example is Airborne 1, a company starting in 1998 virtually from nothing and trying to establish itself through cooperations, attraction of investors, etc.). This policy of alliances seems to be for the moment the wiser, or at least less risky, approach. The situation in the private sector is still unstable and volatile and, thus, it is uncertain how many of the existing companies will survive. This uncertainty has partly created fears and secrecy, especially with firms in USA, and an unwillingness to reveal information about their laser systems, even on important hardware parameters which a potential customer should absolutely know in order to consider the use of a certain laser system for his application. However, it must be mentioned here, that all companies contacted, even though some of them had initial reservations, finally delivered more or less complete information for this article.

There is an evolving specialisation of the companies, e.g., some specialise in very low-altitude appli-

Table 2
Firms/organisations using ALS (excluding manufacturers and non-commercial military systems) and number of systems (UD = under development; for more information on firms/organisations see Appendix B)

	Service providers/ no. of systems[a]		Owners (no services?)/ no. of systems	Bathymetric lasers		Total Firms/ no. of systems
	Owners	Leasing/ renting[b]		Service providers/ no. of systems	Owners/ no. of systems	
Optech ALTM	11/9	6/0	3/3			20/12
Saab TopEye	2/2	1/1				3/3
TopoSyS	1/1 (+1 UD)	2/0				3/1 (+1 UD)
Azimuth	4/2					4/2
Custom/Azimuth components	2/3					2/3
Custom/FLI-MAP	2/2					2/2
Custom/NEC components	1/1		2/2			3/3
Custom[d]	3/6 (+1 UD)			4/3	2/2[c]	9/11 (+1 UD)
Unknown		1/0				1/0
Total	26/26 (+2 UD)	10/1	5/5	4/3	2/2	47/37 (+2 UD)

[a]Among the systems, two profilers, of Nortech and Geographia, are included.
[b]Almost all firms, with the exception of Eurosense, seem to use an ALS system only on given occasions, so these systems are not counted here.
[c]Counting two HawkEye systems for the civilian administration.
[d]Includes systems of TerraPoint, Nortech and Institute of Navigation, University of Stuttgart.

cations for power line and corridor mapping, while other focus on more traditional topographic mapping from higher altitudes. Another trend is internationalisation, e.g., there are cooperations between firms in different countries, or firms are ready to undertake projects abroad.

NASA has played a certain role in the commercialisation of airborne laser scanning or technologies related to it, however, in the opinion of the author, much lower than the one it could play, given its over 25 years experience in this field and the development of many systems for different applications. The fact that certain U.S. firms and organisations, currently involved in ALS, had cooperation with NASA within its Commercialisation Programme on laser scanning, digital imaging or related topics might not be a coincidence.

6. Classification of ALS users and systems

Table 2 summarises the users and systems according to type of user and laser system. Excluding bathymetric lasers, 64% of the users are (co-)owners, 24% lease/rent systems, and 12% are owners mainly only for internal use. The high value of the second percentage and low value of the third one are clearly due to the high system costs and the fact that the

Table 3
Geographic distribution of users and systems listed in Table 2

	Europe[a]	USA	Canada	Japan	Australia	South Africa
Users	19	12	7	5	3	1
Systems	15 (+1 UD)	10[b] (+1 UD)	4.5	5	1.5[b]	1

[a]Countries included: Belgium, Germany, Norway, Russia, Sweden, The Netherlands, UK, Italy.
[b]One system shared in a joint venture between a US and an Australian firm and another one shared between a US and a Canadian firm.

market is not fully developed yet. No civilian administration is owner of an ALS system in N. America and Australia. 33% of the systems used are by Optech, 51% are mainly custom-made, and only 16% by Azimuth, Saab and TopoSys together. Of the manufacturers, except Optech, the one making significant advances recently is Azimuth. Table 3 shows the geographic distribution of users and systems. Europe and N. America each cover 40% of the users and 41% and 39% of the systems, respectively, with the only other significant presence from Japan and Australia. Firms are based in 13 countries in total. Due to leasing, sharing, etc., systems account only for 79% of the number of firms involved in ALS.

7. Platforms

Firms rather focus on either airplanes or helicopters, but lately some providers try to integrate their system in both. Helicopters are typically used in applications where small width, elongated areas need to be mapped (power lines, corridor mapping, topographic and bathymetric mapping along coastlines), in mapping of small areas (airports, open pit mines), when very low altitude (for higher accuracy and denser point measurements) and/or low flying speed is needed (flood mapping), when high manoeuvrability and many high-curvature turns (e.g., following roads in 3D city modelling) are required, or in difficult terrain with abrupt height discontinuities (mountains). Most common helicopters used are the Eurocopter AS350, the MD 500 and Bell 206 series. Typical speeds are 40–90 km/h for helicopters, and usually 160–270 km/h for airplanes, while some systems (e.g., LADS MkII, TopoSys and twin piston-prop airplanes) go up to 280–350 km/h. Typical flying heights are 200–300 m for helicopters, and 500–1000 m for airplanes. Typical flying times for a mission are 2–4 h.

8. Estimation of position and orientation

Most ALS systems use GPS and INS, or more often smaller, more lightweight and cheaper IMUs. Few systems with reduced accuracy requirements and in low-flying platforms use GPS arrays or GPS

Table 4
Specifications of the Applanix POS AV 310 and DG 310 models. The accuracy values for position and orientation are RMS, postprocessing for dual frequency GPS receivers and heading for typical mission profiles and latitudes

		POS AV 310	POS AV 310 (1°/h)	POS DG 310
C/A GPS	Position (m)	< 100	< 100	< 100
	Roll, pitch (°)	0.05	0.035	0.016
	True heading (°)	0.16–0.33	0.085	0.06–0.16
DGPS	Position (m)	1–5	0.75–5	0.5–2
	Roll, pitch (°)	< 0.05	0.03	0.008
	True heading (°)	0.083–0.16	0.075	0.05
Postprocessed	Position (m)	0.1–0.3	0.1–0.3	0.1–0.3
	Roll, pitch (°)	0.016	0.01	0.005
	True heading (°)	0.05	0.02	0.008
Angular resolution (°)		0.0007	0.0007	0.0001
IMU size (cm)		8.9 D × 8.5	8.9 D × 8.5	10.9 D × 11.4
IMU weight (kg)		0.7	0.7	1.6
Range	Gyros (°/s)	± 1000	± 1000	± 160
	Accelerometers (g)	± 40	± 40	± 6
Scale factor (1σ)	Gyros (ppm)	100	100	100
	Accelerometers (ppm)	300	300	100
Alignment (1σ)	Gyros (μrad)	100	100	75
	Accelerometers (μrad)	100	100	75
Bias repeatability (1σ)	Gyros (°/h)	< 5	1	0.5
	Accelerometers (μg)	< 500	300	100
Noise	Gyros ($°/h^{1/2}$)	< 0.1	0.07	0.005
	Accelerometers ($\mu g/Hz^{1/2}$)	50	50	10

and vertical gyros. Differential GPS is used either with ground reference stations, or, particularly in large or inaccessible areas, through receipt of corrections via satellite, e.g., with the Omnistar system. GPS is also used for navigation either in the absolute mode (positional accuracy ca. ±50 m), or, particularly with very narrow swath flights or irregular terrain, with real-time corrections via satellite or telemetry (positional accuracy ca. ±2–3 m). The positional accuracy of the GPS is for most systems ca. 5–15 cm for DGPS and postprocessing, while for the bathymetric lasers that use GPS with real-time corrections the accuracy is 2–5 m.

A large, and continuously increasing, number of system providers and integrators use for positioning and orientation, not only of laser scanners, the system POS of Applanix (www.applanix.com, note that information on the performance of POS systems is quite outdated). Applanix offers two systems for airborne sensors, POS/AV 310 and POS/DG 310, whereby the second one is more accurate, especially in heading. AV 310 comes in two versions, a standard and a 1°/h one that has lower values for bias repeatability and noise (Table 4). All three models use a 12-channel, low noise, DGPS-ready, single or dual frequency GPS receiver and can output time tag, status, position, attitude, velocity, track and speed, dynamics, performance metrics and sensor data with a rate of up to 200 Hz to a removable PCMCIA disk. The two AV 310 versions use an LN-200 fiber optic gyro IMU with 5 and 1°/h gyro bias repeatability, respectively. The DG 310 uses AIMU (Applanix IMU), a custom-made product of Inertial Science Inc. (ISI). This IMU seems to be a modified version of the DMARS/ITAG product of ISI. DMARS (Digital Miniature Attitude Reference System) was developed in cooperation with Sandia National Lab. and offers small size and weight, low power consumption, high accuracy, low cost, enhanced self-align, integration with GPS, digital processing and versatility. About half of the ALS systems use POS. Systems for low-attitude applications tend to use the AV 310 (1°/h) model, while those flying high (up to 6100 m) use the DG 310 one. Some of the Applanix systems are equipped with older IMU models (LTN-90, LR-86). Due to hardware and software developments and differences, the specifications for angular resolution and accuracy given in Table 5 for various ALS using Applanix differ. Accuracy tests with a photogrammetric camera, which has a more stable geometry than a laser and no scanning mirror(s), and an Applanix system POS/DG with an LR-86 IMU from 1-km altitude has resulted in accuracies (standard deviation) of 10–20 cm for the position and 0.005–0.01° for the rotation angles, whereby in some cases a significant bias was observed as well as local errors up to 0.6 m in position and 0.025° in rotations (see Hutton and Lithopoulos, 1998). These results come from a comparison with aerial triangulation, while a comparison to surveyed ground points gave an accuracy (standard deviation) of 15–25 cm and almost equally large bias.

Other commonly used INS include the Honeywell H-764 and H-764-G. The latter has embedded GPS capabilities (available for the military only), measurement rates up to 200 Hz, and uses the GG1320 digital laser gyro and Allied Signal QA 2000 accelerometer. These systems are larger, heavier and need more power than the AIMU system.

9. Accuracy

The specifications of the most crucial parameters listed in Table 5 below, i.e., those referring to accuracy, are the most uncertain. Some firms give only range accuracy or simply accuracy, without separate indication for planimetric and height accuracy. Almost none of the firms gave the acquisition parameters for which their accuracy indicators are valid (e.g., flying height, scan angle, terrain roughness and inclination, reflectivity and 3D size and shape of target objects, etc.). There is rarely an indication of how the accuracy was checked, how many reference points were used, with what types of terrain and land cover, and what the accuracy represents (given specifications include: 1σ, shot-to-shot relative accuracy, 95%, average and standard deviation of absolute errors, RMS, CEP 95%, etc.). Although one could claim that such detailed information would not fit in this overview paper, the fact is that there are very few published, thorough and objective accuracy tests on ALS. The reader should consider that the accuracy values given in Table 5 might be for rather optimal conditions (one firm, e.g., mentions that the specified accuracy is valid only for flat objects under the condition that the laser footprint is 100% included within the target; however, this statement is made in a detailed technical description, that is not commonly available). Independent accuracy investigations (Hoss, 1997; Kraus and Pfeifer, 1998; Murakami et al., 1999) have shown that, depending on terrain slope and cover, lower accuracies, especially in planimetry, than those mentioned in Table 5 are achieved. Another open topic is accuracy investigations, especially for the rotation angles, for high-altitudes (>1000 m). This becomes increasingly important since more and more firms offer systems for altitudes from 2000 to 6000 m over ground. Such investigations have been performed but the results have not been disclosed.

10. Sensor integration

Many systems use video, mainly for documentation or visual inspection. However, the quality and resolution of video is limited, a true spatial and temporal co-registration between laser and images is in most cases not accomplished, and a thorough camera calibration is missing. Thus, geocoding, if performed, is of poor geometric accuracy and low resolution. Other sensors that have been used include digital CCD cameras with 2000^2–4000^2 pixels and photogrammetric film cameras (both from mapping companies and rather high-altitude flights), while in one case a combination with interferometric SAR was performed, and in another an integration with multispectral linear CCDs is planned.

11. Software

Software is one of the most critical components, which can give a leading edge to one or another firm, and produce useful information out of a huge amount of raw data. Many packages, as shown in Table 6, are commercial programmes. These programmes are often used by various companies, especially in the early processing stages. However, when it comes to more specialised and difficult tasks like object filtering, separation and classification, firms use custom-made in-house solutions, involving, we suspect, quite a large amount of manual editing. There is very little known about software and methods on calibration of ALS systems both statically and in-flight (offsets and misalignment between laser, INS, GPS, other sensors, etc.), correct interfacing and synchronisation among the various components, correction of inconsistencies between strips and use of tie and control points, calibration of cameras, etc. These aspects have, however, an important influence on the geometric accuracy of the result, and here is where the expertise of one or another company can make a big difference. The fact that there are no standard procedures on how these tasks should be performed makes the evaluation of the performance of each company with respect to these aspects even more difficult.

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Appendix A. A survey of commercial ALS systems

A.1. Notes

- Laser scanner system parameters can vary rapidly due to technological developments. Information on Japanese systems is scarce. Published information on system parameters is sometimes contradictory due to errors, even within the same information source, or differences of theoretically identical systems because of different time reference, and thus level of technological development. The information in Tables 5 and 6 is not 100% complete but correct to the best of our knowledge. A questionmark (?) indicates uncertain information which could not be verified. More detailed information can be acquired from the system/service providers.

• Some manufacturers, like Optech and Azimuth, can produce systems, adjusted to the customer requirements, and thus with partly different parameters than the ones listed in Table 5.

• Tables 5 and 6 contain only commercial systems (sold or used), i.e., no experimental/research or military systems.

• Some of the missing parameters, e.g., laser footprint and swath width, and to a lesser extent (since they depend on many variable parameters) x- and y-point spacing, point density and covered area, can be derived, at least approximately, by using the formulas in (Baltsavias, 1999).

• The minimum flying height is typically identical to the eyesafe distance. Regulations, varying from country to country and for land cover type (urban, rural), about minimum flying height should also be observed.

A.2. Systems with limited information

A.2.1. Laser range finders and scanners of RIEGL Laser Measurement Systems

Among the LRFs, the following, which are not too limited in range, will be shortly described.

• LD90-3300 VHS: range 2–400 m (80% target reflectivity) and 5–120 m (10% target reflectivity), accuracy (standard deviation, plus distance depending error 20 ppm) typically 5 cm/ worst case 10 cm, measurement resolution 2 cm, pulse rate 2 kHz, 1st echo only, wavelength 0.9 μm, beam divergence 3 mrad × 0.5 mrad, Class 3B (for scanned beam, Class 1), power supply 11–18 VDC (20–28 VDC option), operational temperature −10–50°, dimensions 20 × 13 × 7.6 cm^3, weight 1.5 kg.

• LD90-3300 EHS: range 5–300 m (80% target reflectivity) and 10–100 m (10% target reflectivity), accuracy 10 cm (standard deviation, plus distance depending error 20 ppm), measurement resolution 10 cm, pulse rate 12 kHz, 1st echo only, wavelength 0.9 μm, beam divergence 3 mrad, Class 3B (for scanned beam Class 1), power supply 11–18 VDC, operational temperature −10–50°.

• LD90-3800 VHS-LP: range 400 m/750 m for target reflectivity 10%/80%, respectively, accuracy 10 cm (standard deviation, plus distance depending error 20 ppm), resolution 5 cm, resolution and accuracy of next-to-last target 0.5 m, minimum distance between two targets (depending on echo amplitude) 2–5 m, pulse rate 2 kHz, Class 1 for scanned beam, wavelength 0.9 μm, divergence < 2 mrad, last or next-to-last target return selectable, echo amplitude also recorded, power supply 11–18 VDC, operational temperature −10–50°, dimensions 25.2 × 18.4 × 10 cm^3, weight 4.4 kg.

• LD90-3800 EHS-LP: like above but with 10 kHz pulse rate, also the range difference between last and target next to the last is provided.

RIEGL produces the following laser scanners.

• 3D Imaging Laser Mirror Scanner LMS-Z210: scan angle 80° with unidirectional rotating polygon, scan rate 20 Hz, angle step width 0.24°, angle readout accuracy 0.036°, slow scan of complete optical head 300°, echo amplitude recorded, RIEGL SCAN software for data acquisition and real-time display (Win95/WinNT), range 150–350 m for target reflectivity 20%/80%, respectively, minimum range 2 m, accuracy (standard deviation, plus distance depending error 20 ppm) typically 2.5 cm/ worst case 10 cm, measurement resolution 2,5 cm, pulse rate 20 kHz, wavelength 0.9 μm, beam divergence 3 mrad, Class 1 for scanned beam, dimensions 43.5 cm L × 21 cm diameter, weight 13 kg, power supply 11–18 VDC, maximum 3 A, operational temperature −10–50°.

• 2D Laser Mirror Scanner LMS-Q140-60/80: scan angle 60° or 80° with unidirectional rotating polygon, angle step width 0.15° and 0.2°, respectively, angle readout accuracy 0.04°, scan rate 10 Hz, echo amplitude recorded, Q140SCAN software for data acquisition and real-time display (Win95), range 100–350 m for target reflectivity 20%/80%, respectively, minimum range 2 m, accuracy (standard deviation, plus distance depending error 20 ppm) typically 2.5 cm/ worst case 10 cm, measurement resolution 2.5 cm, pulse rate 12 kHz, wavelength 0.9 μm, beam divergence 3 mrad, Class 1 for scanned beam, dimensions with aluminium protecting case 47.4 cm L × 20 cm diameter, weight 12 kg, power supply 11 VDC, maximum 2 A, operational temperature −10–50°.

The scanner above can obviously be used in low-flying helicopters. Using the LD90-3800 series range finders, the maximum flying height could be increased.

Notes to Table 5:

[a]A = airplane, H = helicopter. Helicopter models listed are certified for the respective laser system.

[b]Data in italics show the parameters for the new ALTM 1020 system. Currently used ALTM 1020 have the parameters in standard letters.

[c]Single, custom-made system for the company Aero Asahi. The information given here refers to the use of the system by this firm.

[d]Available from November 1999.

[e]With two lasers.

[f]Some differences between 3001 and EarthData are due to the way each company uses the system and processes the data.

[g]This high maximum altitude is achieved by using a high-peak-power diode-pumped laser source in combination with quite large receiver optics. This means having a rather large scanning mirror and a powerful galvanometer to actuate it. Despite the large optics and powerful laser, overall system size is comparable to that of other manufacturers.

[h]Vertical laser profiler.

[i]It seems that there are three predefined scan angles: 10°, 40° and 60°. Scan can be tilted in flight direction up to 45° from nadir.

[j]Depth range 0.5–70 m. In bathymetric lasers, the maximum depth strongly depends on the water turbidity. Generally, the maximum depth is about three times the Secchi depth. Secchi depth is a measure of turbidity and is defined as the depth of a Secchi disc that is just visible by an observer at the water surface.

[k]Laser bathymeters usually scan in two modes, the normal search and the high resolution mode. The search mode scans meanderwise in parallel arcs at ca. 20° forward angle. The high resolution mode scans vertically meanderwise parallel lines and is typically used when a detailed second look is needed to resolve any discrepancies observed by the operator or to better delineate suspected hazards and obstructions.

[l]Depth range up to 50 m.

[m]Has also shoreline features and topography capabilities. Depth range up to 60 m.

[n]Depth range 0.5–50 m.

[o]For corridor mapping, sometimes km/day are given.

[p]Netto means excluding flying time to/from survey area and time to change flight strips, i.e., only time during which laser measurements are made. This time can depend on flying speed and height, storage capacity, etc.

[q]Minimum distance between two objects along the laser pulse path so that the returned echoes of these objects can be well separated by the receiver.

[r]For one strip and typical flying speed and height, and swath width.

[s]Nominal ground sample distance (GSD) is 3.05 m. Nomimal GSD is a manageable file size product (raw or interpolated data) suitable for most mapping projects down to the 0.5-m contour interval.

[t]A waveform digitiser is a device, in this case, in the laser receiver electronics linked to the output of the detector, for digitising a continuous signal with frequency that can be very high, e.g., 500 MHz. In ALS, waveforms are the backscattered non-saturated echoes from the interaction of a short duration laser pulse with the Earth's surface. They are used in special lasers, e.g., for vegetation, satellite-based ones (SLA-01 and -02), hydrographic, etc., for direct measurement of local surface vertical structure, and in particular, the height of such relief elements as trees, buildings, and geomorphic features. Using appropriate algorithms, parameters like vertical profiles and biomass, total vertical roughness, etc. can be estimated.

[u]VRU: vertical reference unit, usually a vertical gyro, no true INS.

[v]Video cameras with digital DVCAM format (one PAL), 700 lines resolution, time tagged to within 10 μs of GPS time, forward camera with remotely controlled zoom lens.

[w]Sensors listed available only by EarthData.

[x]Plus Trimble 4000 SSi for 3001.

[y]Recording rate per frame < 2.2 s. Lens: 50 mm (45° FOV, accuracy after calibration < 1 pixel RMS over full FOV), 90 mm (30° FOV, accuracy after calibration < 0.5 pixel RMS over full FOV). Minimum pixel footprint 15.2 cm. Image geopositioning absolute accuracy < 0.3 m RMS. Pixel size seems to be 12 μm.

[z]For 600 m scan width, 2000 m h, 185 km/h speed, pixel footprint = 0.3 m, ca. 500 images/h collected, with ca. 40% overlap. Imagery can be registered to: 2–4 m with no GCPs, 1–1.5 m using block correction with no GCPs, 0.7–1 m with block correction and GCPs.

[aa]ρ = reflectance.

[bb]Circular error probable. Statistical measure of precision (usually planimetric) defined as the Nth percentile value of the 2D position error statistic. A CEP value determines the radius of a circle within which N% of the positions measured will fall. N is usually 50, here $N = 95$.

[cc]Apparently, this includes the total costs of the system, including the helicopter.

Table 5
Technical specifications of commercial airborne laser scanner systems

System	Company and/or manufacturer	Platform[a]	Scan principle/ pattern	Wave-length(s) (μm)	Scan angle θ (°)	Pulse rate (kHz)	Scan rate (Hz)	Flying height h minimum–maximum (m)	Swath width (m)
ALTM 1020[b]	Optech	A/H	Oscillating mirror/ Z-shaped	1.047	0–40	0.1–5	0–50, depends on θ, e.g., 30 for 40°, 50 for 20°; *0–99, depends on θ, e.g., 28 for 40°, 99 for 10°*	330–1000 (2000 optional)	0–0.7 h
ALTM 1025	Optech	A/H	Oscillating mirror/ parallel lines	1.047	0–40	25	0–99, depends on θ, e.g., 28 for 40°, 99 for 10°	100–1000	0–0.7 h
ALTM 1025[c] Aero Asahi	Optech	H, AS350B	Bi-direct. two-axis galvanometer mirror/Z-shaped or parallel lines, variable	1.064	0–22.6	25	0–30, depends on θ	65–1000 (150 typical)	0–0.4 h
ALTM 1210	Optech	A/H	Oscillating mirror/Z-shaped	1.047	0–40	10	0–99, depends on θ, e.g., 28 for 40°, 99 for 10°	400–1200 (2000 optional)	0–0.7 h
TopEye	Saab Survey Systems	A/H, AS350 B, BA, B2	Two oscillating mirrors (scan, pitch)/Z-shaped	1.064	0–40 (A) non-stabilised; 0–20 (H) pitch stabilised	≤ 6	4.5–25	200–1000 (A) 60–500 (H) (120–300 typical)	0–0.73 h (A) 0–0.35 h (B)
TopoSys I	TopoSys	A/H, Bell 206	Optical fibres/parallel lines	1.540	14	83	630	60–1000	0.25 h
TopoSys II[d]	TopoSys	A/H, Bell 206	Optical fibres/parallel lines	1.540	14	83	630	60–1600	0.25 h
FLI-MAP I	John E. Chance/ Fugro-Inpark	H, Schweizer 300C modified with arms	Rotating mirror/parallel lines	0.9	60	8	40	20–200	1.15 h
FLI-MAP II	As above	H, MD 500, Bell 206 A/B/L	Rotating mirror/parallel lines	0.9	30–60	12/24[e]	60	20–300	0.54–1.15 h

Table 5 (continued)

System	Company and/or manufacturer	Platform[a]	Scan principle/pattern	Wave-length(s) (μm)	Scan angle θ (°)	Pulse rate (kHz)	Scan rate (Hz)	Flying height h minimum–maximum (m)	Swath width (m)
ScaLARS	Inst. of Navigation, Univ. Stuttgart	A	Nutating mirror/elliptical	0.810	27.2 and 38	7.7	≤ 20 variable	150–700 (500 optimal)	0.48 and 0.69 h
AeroScan 3001/EarthData[f]	3001, EarthData (manufactured by Azimuth)	A, Piper Navajo Chieftains	Bi-direct. oscillating mirror/sinusoidal	1.064	1–75	15	0–25, depends on θ	305–6100[g]	0–1.53 h
AeroScan	Azimuth	A	Bi-direct. oscillating mirror/sinusoidal	1.064	1–45	15 (standard), 25 for low-altitude	0–51, depends on θ	305–3000	0–0.83 h
RAMS	Enerquest (manufactured by Azimuth)	A	Bi-direct. oscillating mirror/sinusoidal	1.064	1–45	0.1–15	0–35, depends on θ	3050 max	0–0.83 h 2210 max
DATIS	EagleScan (LRF manufactured by Azimuth)	A/H	Oscillating mirror/parallel lines	1.057	0–40	5	0–70	1000–2000 (typical 1830–2000)	0–0.73 h, 600–1000 with imaging for orthoimages
ALTMS	TerraPoint (built by HARC with NASA support)	A	Multifaceted rotating mirror/parallel lines	1.064	36	0–30	Variable	450–1500 (typical 900), maximum 6100 under construction	0–0.65 h
SURVAIR Ver 2	Geographia	MD500	Nutating mirror/elliptical scan	904	30	0.1–15, 25 option	15, 30 and 50 fixed steps	30–450	0.54 h

ATLAS-VL[h]	Nortech	H, Bell 206B, AS350, MBB 105B	Profiler/		NA	2	NA	280 (100 typical)	NA
ATLAS-SL	Nortech	A/H			60	12	20	maximum 300–800 (260 typical)	1.15 h
Nakanihon	Nakanihon (LRF manufactured by NEC)	H, AS 350B	Prism/	1.062	0–60[i]	20	25	50–400 (200–400 typical)	0–1.15 h
LADS MkII[j] (Bathymetry System)	LADS Corp. Ltd.	A, de Havilland Dash 8–200	Rectilinear/parallel lines or arcs[k]	1.064, 0.532	27	0.9	18	366 or 500	0.48 h 240 m
Larsen 500[l] (Bathymetry System)	Terra Surveys (manufactured by Optech, upgrades by Terra Surveys)	A	Rotating mirror/elliptical	1.064, 0.532	30	0.02	20	500 typical	0.54 h
SHOALS[m] (Bathymetry System)	US Army Corps of Engineers (manufactured by Optech)	A, Twin Otter/ H, Bell 212	Programmable two-axis mirror/parallel lines or arcs[k]	1.064, 0.532	0–40	0.4	0.3–7	200–800 (200 typical)	0–0.73 h
HawkEye[n] (Bathymetry System)	Swedish government (manufactured by Saab Dynamics and Optech)	H, Bell 212	Programmable two-axis mirror/parallel lines or arcs[k]	1.064, 0.532	0–40	0.2	0.3–7	50–800 (200–300 typical)	0–0.73 h

Table 5 (continued)

System	Beam divergence (mrad)	Laser footprint (m)	Across track point spacing (m)	Along track point spacing (m)	Point density (points/m^2)	Flying speed V min/max/typical (km/h)	Area/h (km^2/h)[o]	Netto[p] flying time max/typical (h)	No. of echoes per pulse/minimum vertical object separation[q]	Intensity recording	Pulse width (ns)
ALTM 1020	0.30	0.3 at 1000 m h				0/−/150		12/4	1st or last, *1st and last*	N, *optional*	10
ALTM 1025	0.30	0.3 at 1000 m h	0.1 at 140 m h, θ 40°	0.5 at 180 km/h, 99 Hz scan rate	0.5–200	0/−/150		4/2	1st and last	optional	8
ALTM 1025 Aero Asahi	0.25, 1.2	0.12 at 100 m h, 1.2 div.; 0.1 at 400 m h, 0.25 div.	0.1 at 100 m h	0.2–0.5 depending on V	20–50	−/−/50–90	1.5–14.5	2.5/2	1st or last	N	8.65
ALTM 1210	0.30	0.3 at 1000 m h				0/−/150		12/4	1st and last	Y	8
TopEye	1, 2 (A) 1, 2, 4 (H)	0.5, 1, 2 at 500 m h	0.25–4	0.5–8	1/16-1 (A); 1–15 (H)	typical 167–185 (A); 36–90 (H)	1–100 161–241 km/day		1st and last or 4/1.5–2 m	Y 128 levels	7
TopoSys I	0.5	0.3 at 600 m h	0.4–1.9	0.06–0.13	5–25	36/300/252	3–10		1st or last	N	
TopoSys II	0.5	0.3 at 600 m h	0.4–3.0	0.06–0.13	3–25	36/300/252	3–20		1st and last	Y	
FLI-MAP I	2	0.2 at 100 m h	0.58 at 100 m h	0.5 at 20 m/s	maximum 10	−/−/36–72	56–161 km/day	−/2	1st	Y	6
FLI-MAP II	2	0.2 at 100 m h	0.58 at 100 m h	0.33 at 20 m/s		−/−/36–72	175 km/day	−/3	1st	Y	6
ScaLARS	2	1.4 at 700 m h	2.4 at 20 Hz scan rate	V (m/s)/scan rate (Hz)	0–5, average 0.3 at 270 km/h and 20 Hz	−/−/270	80[r]	4.75/− with removable HD even longer	NA	Y 13 bit	CW

AeroScan 3001/ Earth Data	0.33	0.33 at 1000 m h	Variable	Variable	0.007–0.5	Aircraft-dependent	Varies, up to 3119 km^2/h	6 h data storage capacity	5/ ~ 2 m	N	12
AeroScan	0.33	0.33 at 1000 m h	Variable	Variable		Aircraft-dependent	Varies, up to 828 km^2/h	12 h data storage capacity	5 (3 for 25 kHz option)/ ~ 2m	N	12
RAMS	0.33	0.33 at 1000 m h	up to 7.6[s] 2–5 typical	2.4–?[s]	0.1 typical	220 typical	As above		5 at 15 kHz / ~ 2 m	N	12
DATIS	0.25	0.25–0.5 at 1000–2000 m h	Variable, typical 5 at 1830 m h, θ 31°	Variable, typical 5 at θ 31°	Variable, up to 1/12	−/−/185	200		1st and last	N	< 10
ALTMS	1	0.9 at 900 m h	Variable	Variable	Variable	−/−/240	140 optimal	5/3	4/0.75	N	7
SURVAIR Ver 2	1	0.1 at 100 m h	0.37 at 100 m h, 30 Hz, 15 kHz	0.75 at v 90 km/h 30 Hz		0/−/90–100			5 (3 for 25 kHz option)	N	3
ATLAS-VL	2.5	0.25 at 100 m h	NA	> 0.01 at 100 m h		−/−/80	< 402 km/day		1st, last, 2nd last		
ATLAS-SL			1.5	2.5		−/−/180	965 km/day				
Nakanihon	2.5	0.75 at 300 m h	0.43 at 300 m h, θ 60°	0.55 at 50 km/h	4.2 typical	−/−/50	17.3 at 50 km/h, 300 m h, θ 60°				
LADS MkII			5 (3, 4 option)	5 (3, 4 option)	1/25, 1/9, 1/16 option	−/−/324 nominal	< 65	8/5.5	Full[t] waveform	Y	
Larsen 500	4	2 at 500 m h	30/15	30		−/−/230	50		Full[t] waveform	Y	12
SHOALS	2–15	2.4	4–7 typical	4–7 typical		0/278/37–222	< 60, 8–32 typical	3 typical	Full[t] waveform	Y	6
HawkEye	2–15	2.4	1–15, 4–7 typical	4–7 typical		0/185/37–81	< 30, typical 18 at 300 m h and 5 m grid		Full[t] waveform	Y	7

Table 5 (continued)

System	Cameras	Ground GPS receivers	GPS receiver	GPS frequency (Hz)	INS	INS frequency (Hz)	Angle resolution (°)	Attitude precision roll, pitch/heading (°)
ALTM 1020	NTSC or PAL (annotated video out)	Sercel NR103T, Trimble 4000/7400, Ashtech Z12 or Rinex 2.0, *any Geodetic grade*	Trimble 4000 SSe, Trimble 7400, Ashtech Z12, *Novatel Millenium, Trimble 7400, Ashtech Z12, Z-Surveyor*	1, *2*	LTN-90 fibre optic ring gyro, Applanix	50	0.01	0.04/0.05, *0.02 / 0.03*
ALTM 1025	NTSC or PAL (annotated video out)	Any Geodetic grade	Novatel Millenium Trimble 7400, Ashtech Z12, Z-Surveyor	2	LTN-90 fibre optic ring gyro, Applanix	50	0.01	0.02/0.03
ALTM 1025 Aero Asahi	NTSC (annotated video out)	Ashtech Z12	Ashtech Z12	1	Applanix POS	50	0.01	0.05
ALTM 1210	NTSC or PAL (annotated video out)	Any Geodetic grade	Novatel Millenium Trimble 7400, Ashtech Z12, Z-Surveyor	2	LTN-90 fibre optic ring gyro, Applanix	50	0.01	0.02/0.03
TopEye	Nadir, forward, time tagged video (PAL or NTSC), 2K×2 digital (all optional)	Trimble 4000 SSi	Trimble 4000 SSi	2	Honeywell H-764 pitch stabilised (H)	50		0.02/0.03
TopoSys I	video		Novatel Millenium OEM board	1	Honeywell H-764 G	64		0.01/0.02
TopoSys II	RGB-linescanner, plus video in helic.	Novatel Millenium (or any other)	Novatel Millenium OEM board	1	Honeywell H-764 G	64		0.01/0.02
FLI-MAP I	Nadir, forward, time tagged S-VHS video	Trimble 4000 SSE	4 Trimble 4000 SSe	2	VRU[u], pitch, roll	40		0.08–0.1/ 0.1–0.15
FLI-MAP II	Nadir, forward, time tagged video[v]	Trimble 4000 SSE		2	Applanix GPS/INS	200 max		0.05/0.08
ScaLARS	Sony DXC-930P, VHS	Trimble 4000 SSi	Novatel Millenium	2	Litton fibre optic gyro LN-200, Applanix	50	0.01	0.017/0.05
AeroScan 3001/ EarthData	RC30, 4K×4K CCD, thermal sensors, microwave radiometers[w]	Ashtech Z12[x]	Novatel Millenium	1	Applanix with Phalanx IMU	50–200	0.001	0.004/0.008

AeroScan	Camera mounting (video or digital) available on scanner housing, camera port available on scanner interface plate	Ashtech Z12, Trimble 4000 SSi, Novatel Millenium	Novatel Millenium	1	Applanix with Inertial Science IMU	50–200	0.001	0.004/0.008
RAMS	4K×4K PAN CCD[y]	Ashtech Z12, Trimble 4000 SSi, Novatel Millenium	Novatel Millenium	1	Applanix with Inertial Science IMU	50–200	0.001	0.004/0.008
DATIS	2K×2K PAN still video[z]	Ashtech Z12 Rinex V 2.0	Ashtech Z12	1	IRU	100	0.005	0.01
ALTMS	Colour video	Trimble	Trimble	1–5	Honeywell laser ring gyro		0.01	0.02/0.05
SURVAIR Ver 2	PAL or NTSC time stamped video	Novatel Millenium or any geodetic receiver	Novatel Millenium	2	GPS interferometric attitude system (three antennas, CMC Allstar 1200)	10	0.05	0.5/0.5/0.2
ATLAS-VL	2 SVHS video, forward, high res. nadir, both time tagged		DGPS		Two-axis vert. stabilisation, VRU			
ATLAS-SL	Video, digital CCD 2K×2K, 10 cm pixel footprint (typical)		DGPS		Three-axis INS			
Nakanihon	3 CCD, 380,000 pixels		3 DGPS (20 cm positional accuracy)	10 (3 DGPS, position and attitude)	Gyro, Applanix optional	10 (3 DGPS, position and attitude)		0.2 (3 DGPS)
LADS MkII	VHS/PAL		DGPS		stabilised platform			
Larsen 500	SVHS video, nadir, time stamped	Ashtech Z12	Ashtech Z12	2	Litton ring laser gyro	10	0.01	0.05
SHOALS	Color nadir video		Ashtech Z-12		Litton LTN-90	64		0.05/0.05
HawkEye	Nadir video	Trimble 4000 SSi	Ashtech Z-12		Litton LTN-90	64		0.05/0.05

Table 5 (continued)

System	Range resolution (cm)	Range accuracy (cm)	Elevation/depth accuracy (cm)	Horizontal accuracy (m)	Laser classification	Eyesafe range (m)	Power requirements	Operating temperature (°C)	Humidity (%)
ALTM 1020	1	2	<15 (1σ)	<1‰ h, *1*	Class IV (FDA CFR 21)	308 (single pulse)	28 VDC at 15A	10–35	0–95 non-condensing
ALTM 1025	1	2	<15 (1σ)	<0.5 at 500 m h	As above	200 (single pulse)	28 VDC at 35A	10–35	As above
ALTM 1025 Aero Asahi	1	<15 (1σ)	<20, for rigid targets	<0.2, for rigid targets	Class IV	40 compensated, 253 non-compensated	28 VDC at 35A	0–40	0–40 (sensor head)
ALTM 1210	1	2	<15 (1σ)		Class IV (FDA CFR 21)	400 (single pulse)	28 VDC at 20A	10–35	0–95 non-condensing
TopEye	1	15 single pulse, 240 m h, 95% or 10–30 (1σ)			Class 3B (EN 60825)	60	28 VDC, 1.6 kW	10–40 (cabin) −15–45 (pod)	
TopoSys I	6	1	<15	<0.5‰ h	Class I (EN 60825) eye-safe	0	28 VDC at 20A	10–40	0–95 non-condensing
TopoSys II	3	1	<15	<0.5‰ h	As above	0	28 VDC at 20A	0–40	As above
FLI-MAP I	1	<5	<10	<0.15	Class I	0	28 VDC at 12A, <250 W		
FLI-MAP II	1	<5	<10	<0.1	Class I	0	28 VDC at 17A		

ScaLARS	0.1	10 (1σ) at ρ[aa] = 30%	< 20, 700 m h, open area	1 at 700 m h, open area	Class IV	150	28 VDV at 10A	10–30	
AeroScan 3001/ EarthData	3	15	15	1	Class IV (ANSI Z136.1)	305 (single pulse)	24 VDC at 35A	0–35	10–90 non-condensing
AeroScan	3 (quantisation (LSB) 0.625 cm)	2–4 (1σ)	20	0.30	Class IV (ANSI Z136.1)	305 (single pulse)	24 VDC at 30A	0–35	As above
RAMS	3		< 30 (RMS)	< 0.3 (RMS)	As above	305 (single pulse)	24 VDC at 30A	0–35	As above
DATIS	5	7.5	15 (1σ)	1	Class IV	314 (single pulse)	12 or 24 VDC, 360 W	0–35	0–95 non-condensing
ALTMS	2	< 15	Variable, 15–60	1–3, typical 1	Class IV	250	28 VDC	non-condensing conditions	non-condensing conditions
SURVAIR Ver 2	2	3		0.1 at 100 m h	Class IIIB	30	28 VDC at 10A	−10–40	
ATLAS-VL	2	20	20						
ATLAS-SL	2	5–20	> 10						
Nakanihon			10–25 at 200 m h	1 at 200 m h		50			
LADS MkII				5, CEP[bb] 95%					
Larsen 500	15	15	30	5, < 1 for photogr. applic.		500	28 VDC at 70A	−10–50	0–95, non-condensing
SHOALS		15	15	5, 95% DGPS, 2, 95% KGPS	Class IV	160	28 VDC at 110A	0–40	0–95
HawkEye			30	3	Class IV	160	< 5 kW		

Table 5 (continued)

System	Sensor dimensions (cm)	Sensor weight (kg)	Sensor mount	Control rack	Control rack dimensions (cm)	Control rack weight (kg)	Data storage/ acquisition duration	Software	System cost (M USD)
ALTM 1020	29×25×43	12.5	Fits all existing camera mounts, or can be directly mounted to the floor	One stackable vibration-isolated transportable case	60 × 60 × 65, excluding GPS	60 including shipping covers and cables	8 mm digital tape/12 h	Included (Windows NT)	0.8
ALTM 1025	30×35×40	23	As above	Two stackable	59×48×44	91	8 mm digital tape/6 h	Included (Windows NT)	1.6
ALTM 1025 Aero Asahi	58×30×41	23	Bored hole on cabin floor	three stackable vibration-isolated transportable cases	Three 48×58×56	3×35	8 mm DAT	Included (Windows NT)	3.5[cc]
ALTM 1210	29.6×32×55.5	20	Fits all existing camera mounts, or can be directly mounted to the floor	One stackable vibration-isolated transportable case	60 × 60 × 71 excluding GPS	60 including shipping covers and cables	8 mm digital tape	Included (Windows NT)	1.0
TopEye	40×70×250	230		Two (H) or one (A) 19″ racks	Two 60×60 ×60	110	8 mm digital tape, Hi8 VCR, GPS on PCMCIA		1.265
TopoSys I	35×35×35	20	Fits all existing camera mounts, or can be directly mounted on the floor	Two 19″ racks	Two 48×48×40	80	Exchangeable PC HD (>2 GB), 8 mm digital tape		1
TopoSys II	47×53×53	28	As above	One 19″ rack	65×55×45	40	As above	Included (LINUX and Windows)	1.1
FLI-MAP I	15 R×58	11		Integrated in heli			One or two video recorders, removable disks for GPS, laser/2 h	Windows NT	
FLI-MAP II	15 R×58	11		One 19″ rack	53×38×90	68	3 h	Windows NT	

ScaLARS	50×50×85	56	Fits all existing camera mounts, or can be directly mounted to the floor	19″	52×52×110	38	2 GB removable HD	Control software DOS
AeroScan 3001/ EarthData	56×61×93	59	Airframe specific, fits in place of PAV-11 camera mount	19″	48×46×75	110	9 GB removable HD	Windows NT
AeroScan	56×60×93	50	Airframe specific, fits in place of PAV-11 camera mount	19″	48×69×52 (bare rack), 69×71×74 (installed in vibration-isolated shipping container, without front and rear covers)	69 (bare rack), 87 (installed in vibration-isolated shipping container)	18 GB removable HD	Windows NT
RAMS	56×60×93	50	As above	19″	As above	As above	As above	Windows NT
DATIS	60 high, 36 diameter	28	Fits all existing camera mounts	19″	44.5×53.3×63	45	8 mm digital tape/8 h with images	Included
ALTMS	52×72×64	48	Bolted above hole on cabin floor	One, electrically isolated, shock resistant rack	54×56×64	90	8 mm DAT, 9 GB HD	Custom, UNIX
SURVAIR Ver 2	30×20×40 including mirror and power supply	6.5	Mounting for MD500 cargo pod	19″ standard rack, 9 HU height	42×52×40	15	Hard disk and Jaz drive	Windows 98
ATLAS-VL								
ATLAS-SL								
Nakanihon			External pod				8 mm digital tapes	
LADS MkII							DLT, video tapes	
Larsen 500	150×50×50	90	Fits all standard aerial camera mounts	Two 19″ racks	110×80×40	60	4 GB removable HD	Included
SHOALS	60×60×200	300	Pod for helic.	Two 19″ racks	Two 100×55×75, one 35×50×75	300	8 mm tape	
HawkEye	60×55×400	570	Pod	Two racks	100×50×60		8 mm tape	

Table 6
Processing software for airborne laser scanner systems (O = own, T = third party)

System	Mission planning	GPS/INS postprocessing	Geodetic transformations[a]	Laser point thin-out[b]	Display and visualisation[c]	DTM interpolation, derived products[d]	Point (object) filtering[e]	Point (object) classification[f]	Overlay of laser points on images[g]	Orthoimage generation[h]
ALTM 1020	Y, O	Y, O[i]	Y, O[i]	Y, O[j]	Y, T[k]	Y, O and T	Y, O[i]	Y, O	Y, T	Y, T
ALTM 1025	Y, O	Y, O[i]	Y, O[i]	Y, O[j]	Y, T[k]	Y, O and T	Y, O[i]	Y, O	Y, T	Y, T
ALTM 1025 Aero Asahi	Y, O	Y, T[l]	Y, T[l]	Y, T[m]	Y, T[m]	Y, O and T	Y, T[l]	Y, O	Y, O	Y, O
ALTM 1210	Y, O	Y, O[i]	Y, O[i]	Y, O[j]	Y, T[k]	Y, O and T	Y, O[i]	Y, O	Y, T	Y, T
TopEye[n]	Y, O	Y, T	Y, T		Y, T	Y, T	Y, T	Y, T		
TopoSys I and II	Any third party	Y, T (GeoGenius)	Y	N	Y	Y	Y	N	Y	Y
FLI-MAP I[o]	Y	Y, multi-ref.	Y	Y	Y	Y	Y	Y	Y	
FLI-MAP II[o]	Y	Y, multi-ref.	Y	Y	Y	Y	Y	Y	Y	
ScaLARS		Y, T (POSProc, GrafNav, POSPac)[p]	Y, O	Y, O	Y, O and T (PCI)	Y, T (PCI)	Y, O under test		NA	NA
AeroScan 3001/EarthData	Y, O	Y, T (PNAV, GrafNav, POSPac)[p]	Y, O	Y, O	Y, T[q]	Y, T[q]	Y, O	Y, O	Y, T	Y, T
AeroScan	Y, O	Y, T (GrafNav, POSPac)[p]	N	N	Y, O	Output compatible with a variety of TIN/contour software	N	N	N	N
RAMS	Y, O	Y, T (GrafNav, POSPac)[p]	Y		Y	Y	Y			Y
DATIS	Y, O	Y, T (Grafnav)	Y, O	Y, O	Y, T (Terramodel, IDL, PCI)	Y, O	Y, O	Y, O	Y, O	Y, O
ALTMS	Y, O	Y, T	Y, T	Y, O	Y, T	Y, O and T	Y, O and T	Y, O	Y, T	Available June 99
SURVAIR Ver 2	Y, O	Y, T[r]	Y, T[r] and O[u]		Y, T[s]	Y, T[t]	Y, O[u]	Y, O	Y, T[v]	Y, T[v]
Larsen 500[w]	Y, O	Y, T (WIN-PRISM)	Y, T (GEOCALC)	Y, O	Y, O	Y, T	N	N	Y, O	Y, T (PCI)
SHOALS[w]	Y, O	Y	Y	Y	Y	Y				
HawkEye[w,x]	Y	Y	Y			Y, T (IRAP)[y]				

A.2.2. Other systems

• System of Tokyo Electric Power: 9.8 kHz pulse rate, 1570 nm wavelength, 114 m range, helicopter based, NEC laser.

• System of Kyushu Electric Power: 20 kHz pulse rate, 1047 nm wavelength, 80 m range, helicopter based, NEC laser.

• SURVAIR of Geographia: laser profiler, gyro-stabilised IR-laser, filtering of disturbances with included software, 75–100 km of profiling per day, accuracy < 10 cm, time stamped video camera.

• PS 100 of IBEO: profiler, 100 m range, 2 kHz pulse rate, 905 nm wavelength, intensity recording (40 grey levels), 10 ns pulse width.

• PS 500 of IBEO: 500 m range, 0.8 kHz pulse rate, 905 nm wavelength, intensity recording, 5 cm range accuracy, 2 mrad beam divergence, up to 32 sensors arranged along a line.

• AIMS 1000 (old system of Southern Applied Technologies; company does not seem to be active in ALS any more): 1064 nm wavelength, 320 m range, 20 ns pulse width, 30 cm range accuracy,

Notes to Table 6:

[a] Transformations from WGS 84 to local coordinate or other systems.

[b] Intelligent, adaptive thin-out to keep laser points at objects of interest and reduce the rest.

[c] Display and visualisation of raw or grid interpolated laser points.

[d] Regular grid DTM interpolation and derived products (contours, 3D perspective views, volumes, profiles, etc.).

[e] Filtering-out of objects (e.g., vegetation, buildings) to get the terrain or the opposite, e.g., filtering-out of terrain information to get top surface of vegetation.

[f] Capability to detect objects (buildings, power lines, vegetation, etc.) based on 3D and possibly image information.

[g] Capability to overlay and display arbitrary laser points based on their 3D coordinates and maybe acquisition time on images acquired by the laser scanner system.

[h] Capability to generate orthoimages from the images acquired by the laser scanner system; requires camera calibration, interior and exterior orientation of the cameras, digital images.

[i] The software is delivered but not actually developed by Optech. It includes software by TopScan.

[j] Also using Microstation Surfer.

[k] MapInfo Vertical Mapper, Microstation Surfer, Terramodel.

[l] TopScan software.

[m] Microstation Surfer, etc.

[n] Data visualisation, etc. include TerraModeler and TerraScan by Terrasolid, which includes basic object filtering and classification (both embedded in Microstation, have been used also with Optech's ALTM) and Vulcan by Maptek.

[o] FLI-MAP data after preprocessing are processed by FLIP7 (Windows 95 or NT), a software package which can be leased. It allows geodetic transformations, data (range and intensity) manipulation and visualisation, distance measurements, CAD functionality (e.g., marking of structures, 3D object extraction by manual drawing, combination of objects to layers, object attributing with user-defined attributes each with predefined descriptions, attribute listing for any data point, etc.), object classification/data reduction through filters (ground, wire, pole, rail, etc.), access of video images (using the program VcrController), image orthorectification, TIN DTM generation, data export. Other commercial programs for processing of preprocessed FLI-MAP data include PLS-CADD by Power Line Systems and TLCADD by LineSoft for power line analysis, modelling and design, and TerraModel by Spectra Precision Software (formerly PLUS3 Software).

[p] PNAV by Ashtec, GrafNav by firm Waypoint Consulting (for DGPS postprocessing), POSPac by Applanix (for creation of aircraft trajectory data) and the AeroScan Post Processor (for processing aircraft trajectory and scanner data into WGS84). POSPac runs under Windows NT or 95 and includes GUI, utility functions, GrafNav and POSProc. POSProc implements a strapdown navigator, Kalman filter and smoother to compute a best estimate of trajectory.

[q] EarthData uses own software.

[r] Novatel Softsurv program included in the system.

[s] Intergraph Siteworks included in the system, Surfer, Mapinfo Vertical Mapper can also be used.

[t] Intergraph Siteworks software included in the system.

[u] Geographia 3P software.

[v] Intergraph Siteworks included in the system.

[w] Software required for laser bathymeters also include tidal corrections, wave corrections, spike filtering, waveform analysis and classification of soundings, quality assessment, and possibly video review.

[x] In the Indonesia project of HawkEye, due to the high data amount (1 GB/h), the postprocessing is done on board of a helicopter-carrying vessel using a Unix workstation and only X, Y, Z coordinates are transmitted via satellite to the production center.

[y] Interactive Reservoir Analysis Package.

4 kHz pulse rate, 100 Hz scan rate, 2.5 mrad beam divergence, oscillating mirror, Z-shaped scan pattern, 12° scan angle.

A.3. Commercial systems

See Tables 5 and 6.

Appendix B. Contact and other information on commercial, non-commercial and research ALS systems and other links

Notes: • Almost all WWW addresses below have been accessed in May 1999. Later changes are possible.

• Firms, organisations, etc. in each section are listed in alphabetical order.

• When two addresses are mentioned 1st is mail address, 2nd is visiting address.

• Symbols

O: owners of systems (either directly or through their affiliates, mostly through joint ventures);
L: firms leasing or renting systems from other firms;
CS: commercial system;
OS: custom-made/own-developed system;
S: service providers (O or L, CS or OS);
P: firms selling systems (O and CS, and possibly S);
Systems sold or used in [].

B.1. Commercial ALS companies

B.1.1. Manufacturers

Azimuth (P, O, CS) [AeroScan]. 13 Park Drive, Westford, MA 01886, USA, Tel./Fax: +1-978-692-8500/692-8510, info@azimuth.com, www.ultranet.com/~paulxg. Contact: Ron Roth, rbroth@azimuthcorp.com.

Azimuth, although very little known outside N. America, has been active in producing LRFs for more than 10 years. It has supplied systems for military and commercial customers (LRF for Nortech, EagleScan, Southern Applied Technologies, Geographia). Azimuth has developed and is now manufacturing a *scanning* LRF system, called AeroScan for installation in light aircraft. The AeroScan system comes complete with airborne GPS receiver, IMU, laser scanner, data logging, and a laptop-type control computer. Software includes both a graphical user interface (for the laptop computer) and the software mentioned in Table 6. Ground GPS stations and software beyond GPS/INS postprocessing are not included. Azimuth is currently manufacturing under their own name, but AeroScan is also used by a joint venture of 3001 and EarthData (see below), while three more orders (including EnerQuest) are in process. For customers wishing to manufacture their own scanning systems, Azimuth provides a variety of LRF subsystems. This is the approach taken by EagleScan for the DATIS system, using a modified version of the LRY-500 transceiver (see WEB) with the TRAC-400 controller (range counting electronics). Of the offered transceivers, the LRG-90 and LRY-500 models are the most appropriate for ALS, although in the AeroScan system, the LRY-500 laser source is essentially combined with the LRY-1000 receiver and the PRAM 5000 controller to maximise altitude capability.

NEC. NEC lasers have been used by different firms providing ALS services, but it is unknown whether NEC provides only the laser or the whole integrated ALS system.

Nortech Geomatics (see Section B.1.3.1.), mainly a service provider using custom-made ALS systems, has recently started selling instruments based on their ATLAS-VL and -SL designs, providing a choice between profiling and scanning systems.

Optech (P, S, O, CS) [ALTM 1020, 1025, 1210 (Airborne Laser Terrain Mapper)]. 100 Wildcat Road, Toronto ON, Canada M3J 2Z9, Tel./Fax: +1-416-6615904/6614168, general@optech.on.ca, www.optech.on.ca. Contact: Kevin M. Kelly, kevin@optech.on.ca, and for bathymetric sounders Paul LaRocque, paul@optech.on.ca.

RIEGL Laser Measurement Systems (P, O, CS). (Headquarters) A-3580 Horn, Riedenburgstr. 48, Austria, Tel./Fax: +43-2982-4211/4210, office@riegl.co.at, www.riegl.co.at.

RIEGL USA, 8516 Old Winter Garden Road, Suite 101, Orlando, FL 32835, USA, Tel./Fax: +1-407-294-2799/294-3215, rieglusa@compuserve.com.

RIEGL is producing different LRFs and scanners which can be used mainly in low-altitude flying platforms (see Appendix A).

Saab Survey Systems (P, S, O, CS) [TopEye]. Box 1017, SE-551 11 Jönköping, Sweden, Tel./Fax: +46-36-194800/194588, info@survey.combitech.se,www.combitech.se/survey. Contact: Lars Jaensson, Lars.Jaensson@survey.combitech.se, Hakan Sterner, Hakan.Sterner@survey.combitech.se.

The TopEye system is distributed in USA by Lambda Tech International, budgins@lambda-tech.com, www.lambdatech.com/products.htm.

TopoSys (P and S, O, OS and CS) [TopoSys I and II]. Freiherr-v.-Stein-Str. 7, D-88212 Ravensburg, Germany, Tel./Fax: +49-751-366050/3660531, toposys@w-4.de, www.toposys.com. Contact: U. Lohr.

TopoSys has been up to now a service provider using the system TopoSys I. From November 1999, it will make available for purchase its new TopoSys II, while continuing to provide services with TopoSys I.

B.1.2. System component providers

IBEO Lasertechnik (P, O, CS) [PS 100, PS 500]. Fahrenkron 125, Postfach 7103 80, D-22163 Hamburg, Germany, Tel./Fax: +49-40-6458701/64587101.

Provider of laser systems, not complete ALS systems. Company active more in close-range than airborne applications, also produces custom-made systems. Firm's PS 100 E system used as laser profiler in polar ice mapping, PS 500 EL system (laser scanner) used in topographic and polar ice applications.

Laser Technology. 7070 S. Tucson Way, Englewood, Colorado 80112, USA, Tel./Fax: +1-303-649-1000/649-9710, info@lasertech.com, www.lasertech.com. Contact: John Glennon.

Firm produces mainly ground-based laser systems. Also the Criterion Aerial Laser system but information on its specifications is very limited (dimensions: $8.9 \times 12.7 \times 20.3$ cm^3, weight: 1.8 kg, maximum range: 450 m, accuracy: 3 cm (1σ) and 15 cm (3σ) to a white target at 50 m), while it is questionable whether it can be used as part of an ALS.

B.1.3. Service providers

B.1.3.1. Lasers for topographic applications.

Service providers owning systems directly or through affiliates

3001, The Spatial Data Company (formerly Vernon F. Meyer and Assoc.) (S, O, CS) [ALMS (AeroScan Laser Mapping System)].

5525 Mounes, Suite 102, New Orleans, LA 70123, USA, Tel./Fax: +1-504-733-3001/734-8938, www.3001data.com. Contact: Chad J. Hendrix, chadh@3001data.com.

3001 uses the proprietary/custom ALMS system, using the AeroScan LRF of Azimuth, to collect high accuracy terrain elevation data. 3001 in cooperation with EartData have founded a joint venture to develop the Aeroscan system (see below).

Vernon F. Meyer and Assoc., P.O. Box 2149, 600 Cities Service Highway, Sulphur, LA 70664, USA, info@meyerassociates.com, www.meyerassociates.com/.

Company has participated in the Commercial RS Program of NASA, ARC (Affiliated Research Center) Program.

Aero Asahi (S, O, CS) [Optech ALTM 1025]. Minamidai 3-1-1, Kawagoe, Saitama, 350-1165, Japan, Tel./Fax: +81-492-44-7778/+81-492-42-2676, asahi@mse.biglobe.ne.jp, www.aeroasahi.co.jp/. Contact: Kazunori Takada, 3-1-1 Higashi-Ikebukuro, Tosima-Ku, Tokyo, Japan, Tel./Fax: +81-3-3988 9681/3988 9687. Services: mainly power line monitoring.

AeroFocus Geomatics (S, O, CS) [Saab TopEye]. 2010, 605 5th Avenue S.W., Calgary, Canada T2P 3H5, Tel./Fax: +1-403-269-2252/269-8353. Contact: Chris Tucker, ctucker@focus.ca or Craig Glennie, cglennie@focus.ca, www.focus.ca/AeroFocus/afg_main.html. AeroFocus Geomatics is the result of a joint venture between The Focus Corp. Ltd. and Aerotec LLC (see below). The Focus Corp. Ltd. is one of Canada's largest legal land surveying companies and provides land surveying, engineering, GPS training and applications, GIS, mapping, consulting and project management services. AeroFocus uses a helicopter or fixed wing aircraft and provides a variety of airborne digital mapping products: high resolution colour digital images, digital orthoimages, high accuracy DEMs, oblique airborne images for

GIS inventory, transmission line thermal ratings and plan and profile drawings. AeroFocus uses the TopEye ALS system of Aerotec.

AerotecUSA LLC (S, O, CS) [Saab TopEye]. 560 Mitchell Field Rd., Bessemer, AL 35022, USA, Tel./Fax: +1-205-4286444/428266, www.aerotecusa.com/.

Aerotec bought Airborne Remote Mapping (ARM), a firm in USA for power line surveying using TopEye, in combination with video. Aerotec owns two Saab TopEye systems and specialises in power line surveying, but recently extended its projects to corridor mapping and surveying of small airports. Their ALS system can be combined with high resolution digital, infrared and multispectral cameras.

Air Reconnaissance (S, O (sharing the system of Airborne Laserscanning International (ALI)), CS) [Optech ALTM 1020]. Arthur St., Barwell, Leicestershire, LE9 8GZ, UK, Tel./Fax: +44-1455-851252/840285, www.nrsc.co.uk/public/air_recon/recon1.html. Contact: Keith Mann, kmann@nrsc.co.uk, or John Murtagh, Tel./Fax: +44-1455-849213/841785, jmurtagh@nrsc.co.uk.

Joint venture of NRSC (National Remote Sensing Center, a private UK company) and Atlantic Reconnaissance (the firm Merrett Survey Partnership is also affiliated). ARL is a member of the ALI consortium (see below). In addition to the ALS system, other sensors (CASI, thermal scanner photogrammetric camera, digital video, magnetometer) can be used. Initial applications include line of sight estimation for telecommunications and flood plain mapping.

Airborne Laserscanning International b.v. (ALI) (S, O, CS) [Optech ALTM 1020]. Koningslaan 35, 1075 AB Amsterdam, The Netherlands, Tel./Fax: +31-20-5730330/5730333. Contact: Jan Willem van der Vegt.

Consortium of firms Geodan (Netherlands), TopScan (Germany), NRSC (UK) to share one system.

Aquater S.p.A. (S, O, CS) [Optech ALTM 1210]. Via Miralbello 53, San Lorenzo in Campo (PS), I-61047, Italy, Tel./Fax: +39-0721-731341/731387, prown@aquater.eni.it. Aquater belongs to the ENI Group and provides services in land, environmental and natural resource engineering. Since 1995 Aquater has performed tests and pilot projects using an ALTM 1020. The firm has recently bought an ALTM 1210, which can be integrated with other sensors like CASI, and will be used in projects relating to corridor infrastructure and city mapping, landslide, coastal and powerline monitoring, flood risk mapping and mining assessment.

Asia Air Survey (S, O, CS) [Optech ALTM 1020]. 2-18, Shinjuku 4, Shinjuku-ku, Tokyo 160, Japan, Tel./Fax: +81-3-53792891/53792890, www.ajiko.co.jp/english/aas.htm. Contact: Yoshiaki Takahashi, tak.yoshi@tko.ajiko.co.jp, Tel./Fax: +81-462-23 7261/23 7926. Services: mainly power lines.

EagleScan (S, O, OS) [DATIS (Digital Airborne Topographic Image System)]. 1770 Range St., Suite B, Boulder, CO 80301, USA, Tel./Fax: +1-303-4739100/4739111, info@eaglescan.com, www.eaglescan.com. Contact: Rob Eadie.

DATIS data products partly developed in collaboration with NASA/Stennis Space Center (Earth Observation Commercial Applications Program (EOCAP) 1994). It incorporates a LRF from Azimuth and a digital camera permitting generation of DEMs and digital orthoimages from the same data collection mission. EagleScan is also leasing its system to other firms. DEMs from DATIS sold also by I^3 (Information, Integration and Imaging).

EarthData (S, O, CS) [ALMS]. EarthData is a spatial data, mapping, and GIS services company that provides its clients with customised products and services to support a wide range of land-use and natural resource management activities. The EarthData group represents one of the largest spatial data organisations in the world and consists of the six member companies that are listed below. In 1997, EarthData Technologies (at that time Photo Science), in cooperation with 3001 (at that time Vernon F. Meyer and Assoc.), formed a joint venture called LIDAR Technology, LLC to develop a proprietary system (the ALMS) specifically for aerial mapping and airborne remote sensing applications. The scanner's innovative custom design, which also utilises the latest technology in airborne positioning and orientation, enabled optimisation of the system to collect high accuracy terrain elevation data for applications such as DTM generation, topographic contouring, and automated feature extraction. The EarthData group also owns and operates three Piper Navajo Chieftain aircraft with RC30 dual configuration aerial camera systems, airborne GPS and inertial measuring units to provide additional geospatial data and aerial mapping products. These services, as well as laser scanning capability, are offered through any of the EarthData International offices. The EarthData group may be contacted at the following E-mail addresses:

— holdings@earthdata.com [EarthData Holdings]
— technologies@earthdata.com [EarthData Technologies, LLC]
— international-md@earthdata.com [EarthData International of Maryland, LLC, formerly Photo Science]
— international-nc@earthdata.com [EarthData International of North Carolina, LLC, formerly Piedmont Aerial Surveys]
— international-nm@earthdata.com [EarthData International of New Mexico, LLC, formerly Earth Data LLC]
— aviation@earthdata.com [EarthData Aviation, LLC, formerly Aero Contractors] www.earthdata.com. Contact: Debbie Simerlink, EarthData Technologies, 18227 Airpark Drive, Hagerstown, MD 21742, USA, Tel./Fax: +1-301-733 1176/733 4906, dsimerlink@earthdata.com

EnerQuest Systems LLC (S, O, OS) [RAMS (Remote Airborne Mapping Systems)]. 717 17th Street, Suite 1400, Denver, CO 80202, USA, Tel./Fax: +1-303-2989847/2929279, www.enerquest.com. Contact: Don Wicks, President, dwicks@enerquest.com or Mark E. Romano, Vice President, romano@enerquest.com.

RAMS has the capability to simultaneously collect terrain data and digital imagery, with the largest format CCD currently employed in ALS, at a swath width of over 2100 m at practical rates exceeding 220 km/h flying speed. Collaboration with NASA/Stennis Space Center (EOCAP 1997) on digital airborne imaging.

EnerQuest Systems PTY Ltd. (S, O, OS) [RAMS]. 35 Yarraville St., Robina QLD 4226 Australia, Tel.: +61-7-5593-2772. Contact: Montgomery Omodei or Mal Hentschel, hentschel.malcolm.mh@bhp.com.au.

The firm is a 50/50 joint venture between BHP Engineering, Land Technologies section (Australia) and EnerQuest Systems (USA) to establish and operate an airborne laser mapping business in Australia, Indonesia and Papua New Guinea. BHP Engineering will be using an ALS developed by EnerQuest and plan to have the first instrument calibrated and in operation in Australia in April 1999. The parent company BHP (Broken Hill Proprietary) is one of the largest firms world-wide in minerals and mining, oil and gas, power and infrastructure. BHP Engineering co-developed the LADS RAN bathymetric laser (see below).

Fotonor (company associated with the firm Blom) (S, O, CS) [Optech ALTM 1020]. P.O. Box 1310, 3205 Sandefjord, Norway; Sandefjord Lufthavn (Airport) Torp, 3233 Sandefjord, Norway, Tel./Fax: +47-33-42-08-00/42-08-01, fotonor@sn.no, www.asprs.org/asprs/resources/directory/f2.html. Contact: Øivind Aase.

Fugro-Inpark (both Fugro-Inpark and John E. Chance and Assoc. (see below) are part of the Fugro Group of companies) (S, O, OS) [FLI-MAP (Fast Laser Image-Mobile Airborne Platform)]. P.O. Box 3000, 2260 DA Leidschendam, The Netherlands; Dillenburgsingel 69, 2263 HW Leidschendam, The Netherlands; Tel./Fax: +31-70-3170700/3170750, info@fugro-inpark.nl, www.fugro-inpark.nl. Contact: H. Haasnoot, Tel.: +31-70-3170744.

Geodan Geodesie (S, O (sharing the system of ALI), CS) [Optech ALTM 1020]. Koningslaan 35, 1075 AB Amsterdam, The Netherlands, Tel./Fax: +31-20-5730330/5730333, info.geodesie@geodan.nl, www.geodan.nl (laser scanning at www.geodan.nl/diensten/vls/index.htm, in Dutch). Contact: P. Looman.

Geodelta (S, L (sharing the system of Fotonor), CS) [Optech ALTM 1020]. Ingenieursbureau Geodelta, Oude Delft 175, 2611 HB Delft, The Netherlands, Tel./Fax: +31-15-215-8188/215-8154, info@geodelta.com, www.geodelta.com.

Geodelta has formed together with Blom and Fotonor (see above) a consortium to offer ALS services. They have already done some projects for derivation of DEMs for Rijkswaterstaat, The Netherlands.

Geographia (S, O, OS) [SURVAIR profiler, SURVAIR Ver 2 scanner]. Virkesvägen 10, SE120 30 Stockholm, Tel./Fax: +46-8-640-90-09/640-71-80, geographia@geographia.se, www.geographia.se/. Contact: Ingemar Bengtsson, ingemar.bengtsson@geographia.se or Staffan Nyblom, Tel.: +46-8-6404720 (office), Tel./Fax: +46-155-211414 (hangar), staffan.nyblom@geographia.se.

Geographia is a new company (founded in 1997) active within the field of geomatics. As a result of consulting assignments with landscape information and airborne activities a number of systems for surveying and data collection has been designed. The systems are built in a modular form and have been designed for small helicopters such as the MD500, the Bell 206 and AS350. SURVAIR is a helicopter-based laser profiler for corridor mapping, using an Azimuth LRG-90/PRAM-5000 laser mounted on a stabilised platform. Geographia has developed a laser scanner for helicopter (called SURVAIR Ver 2), which uses a system controller (range counting module) of Azimuth and own scanning mechanism and laser transceiver. The firm is working on a third system which will use a rotating wedge prism, instead of the nutating mirror of the second system, and other scan angle options.

GEOsurv (S, O, CS) [Optech ALTM 1020]. 89 Auriga Drive, Nepean, Ontario, Canada, K2E 7Z2, Tel./Fax: +1-613-8204545/8209772, geosurv@geosurv.net, www.geosurv.net/.

GEOsurv offers airborne laser profiling services to its clients as one of three companies to co-found Laser Map Image Plus, an independently owned company dedicated to the creation of DTMs using laser data. Applications: corridor mapping for roads, railways and transmission lines, flood plain mapping, DTM generation, etc. Projects in North and Central America and Japan.

Laser Map Image Plus. Address as for GEOsurv, Tel./Fax: +1-613-7275490/8209772, info@lasermap.com, www.lasermap.com.

Institute for Navigation, Univ. of Stuttgart (S, O, OS) [ScaLARS (Scanning Laser Altitude and Reflectance Sensor) (semi-commercial)]. Contact: A. Wehr, Inst. for Navigation, Univ. of Stuttgart, Geschwister-Scholl-Str. 24D, D-70174 Stuttgart, Germany, Tel./Fax: +49-711-121-3410/121-2755, aloysius.wehr@nav.uni-stuttgart.de, www.nav.uni-stuttgart.de. System was previously used in cooperation with the firm Geoscan.

John E. Chance and Assoc. (S, O, OS) [FLI-MAP]. 200 Dulles Drive, Lafayette, LA 70506, USA, Tel./ Fax: +1-318-2371300/2370011, info@jchance.com, www.jchance.com. Contact: Larry Schaner, Tel.: +1-303-741 5775, lschaner@jchance.com, Dixie Poche, DPoche@jchance.com.

There are three FLI-MAP systems. FLI-MAP I is intended for airborne corridor mapping and profiling. FLI-MAP II is the new generation of FLI-MAP I, expected to be operational in spring 1999. It is a portable system (i.e., GPS antennas not mounted to special arms or fuselage as with FLI-MAP I, but to a frame holding also the laser and videocameras). FLI-MAP III is intended for airborne asset inventory mapping services. It is actually not a laser based system like FLI-MAP I. FLI-MAP III is actually data and information, with main differences to the FLI-MAP I derived data being digital aerial photographs and information and maps in GIS format.

Nakanihon Air Service (S, O, OS using a commercial laser from NEC or CS?). 1-26-36, Meiekiminami, Nakamura-ku, Nagoya 453, Japan (general address), Tel./Fax: +1-81-52-2326032/221-7827. Contact: Eiji Iwanami, Taku Shibata, 17-1 Toyobawakamiya, Toyoyama-machi 480-02, Japan, eiwanami@cjn.or.jp or ieiji@c-d-k.or.jp, www.nnk.co.jp/chousoku/sekkei/keisoku.html or hkhome.html (in Japanese).

Nortech Geomatics Group (headquarters in Calgary) (S, O, OS, P) [ATLAS-VL, ATLAS-SL, All Terrain Laser Acquisition System].

Nortech Geomatics, 1, 4001A, 19 St. N.E., Calgary, Alberta, Canada T2E 6X8, Tel./Fax: +1-403-2913333/3688, info@nortech-geomatics.com, www.nortech-geomatics.com.

Nortech Geomatics developed the first airborne INS/laser in 1983, a video/laser mapping and profiling system in 1991, a second generation such system (ATLAS-VL) in 1995, and since 1998 the digital image/scanning laser system ATLAS-SL (met also under the name AVITA (Airborne Video Image Terrain Analyzer)). Services: mainly geophysical applications, pipelines, utilities.

Nortech Geomatics USA (subsidiary of Nortech Geomatics Group), 19424 Park Row, Suite 102, Houston, TX 77084, USA, Tel./Fax: +1-281-5999333/5999330, info@nortech-houston.com, www.nortech-houston.com/airlasermapping.html.

Opten (S, O, CS) [Optech ALTM 1020]. Contact: Sergei Cherchik, Semenovsky pereulok, 15, Moscow, 105023, Russia, Tel.: +7-095-360-2453/360-

2517/913-2118/742-7779/742-7781, Fax: +7-095-956-7597/369-5890, Webmaster@opten.cnt.ru, www.opten.cnt.ru/eng/altm/index.html. Emphasis on power line corridor mapping.

TerraPoint (S, O, OS) [ALTMS (Airborne Lidar Topographic Mapping System)]. 4800 Research Forest Drive, The Woodlands, TX 77381-4142, USA, Tel./Fax: +1-877-999-7687, lidar@terrapoint.com, www.terrapoint.com. Contact: Daniel M. Cotter, President, TerraPoint, Tel./Fax: +1-281-364-4081/363-7931, dan.cotter@transamerica.com, or John M. Hill, Director, EISL, Tel./Fax: +1-281-363-7999/363-7931, Jhill@harc.edu, www.harc.edu/eisl.html.

TerraPoint TM LLC was formed in June, 1998 by the Transamerica Real Estate Information Companies (TREIC) and the Houston Advanced Research Center (HARC). TerraPoint combines the business expertise of Transamerica, patented optical technologies of NASA/Goddard Space Flight Center (GSFC) and the research capabilities of HARC. The business purpose of TerraPoint is to commercialise and develop digital topographic products and services based on airborne laser scanning. As part of the agreement for the formation of TerraPoint, this prototype instrument and intellectual knowledge is owned by TerraPoint, LLC.

In 1991, NASA's Commercialization Office at GSFC and HARC entered into a cooperative agreement to develop a miniaturised version of the NASA ALTMS suitable for supporting commercial needs for terrain mapping. A prototype was successfully constructed by HARC's Environmental Information Systems Lab (EISL), with support from NASA and industry sponsors. Other agencies, such as FEMA (Federal Emergency Management Agency, interested in flood mapping), USGS and the US Army Corps of Engineers, supported field testing and proof-of-concept studies. This included tests of the functional prototype performed with commercial, photogrammetric aircraft. In addition to the prototype ALTMS instrument, TerraPoint has finished construction of two additional instruments. These systems are presently being used in N. America and can be flown on light aircraft. A fourth instrument is currently under construction and will incorporate patented optical technologies developed by NASA (to which TerraPoint has exclusive access), i.e., G. Schwemmer's patented 'Conically Scanned Holographic LIDAR Telescope' (patent initially earned him $500, while it could have a $40 million impact on the economy), and possibly other technologies derived from the ATM-III or RASCAL NASA instruments. The new optics are expected to result in flying heights of up to 6100 m. TerraPoint instruments are available for lease to key business partners.

TopScan (S, O, CS) [Optech ALTM 1020]. Münsterstraße 19, D-48565 Steinfurt, Germany, Tel./Fax: +49-2552-98750/98751, info@topscan.de, www.topscan.de. Contact: P. Friess, friess@topscan.de.

Waggoner Engineering (S, O, CS) [Optech ALTM 1020]. 825 N. President St., P.O. Box 23486, Jackson, MS 39202, USA, Tel./Fax: +1-601-3559526/3523945, survey@waggonereng.com, www.waggonereng.com/. Contact: Emad Al-Turk.

Services: laser terrain mapping, laser topographic surveys, laser data acquisition surveys as well as conventional surveys and GPS surveys.

Service providers leasing ALS systems

Aerodata Int. Surveys (co-operate with TopoSys) (S, L, OS) [TopoSys I]. Luchthaven B31, B-2100 Deurne, Belgium, Tel./Fax: +32-3-2813201/2813198, info@aerodata-surveys.com, www.aerodatasurveys.com/services/scanning.htm.

Airborne 1 (S, L, CS) [Optech ALTM 1020]. Contact: Todd Stennett, 214 Main St. #105, El Segundo, CA 90245, USA, Tel./Fax: +1-310-4141400/322 0007, info@airborne1.com, www.airborne1.com.

Airborne 1 is the offspring of a consulting engagement regarding technology transfer with the Center for Technological Innovation, a joint venture between NOAA and IC2 of Univ. of Texas at Austin, a business incubator. Airborne 1 is offering services using, at least theoretically, various ALS systems depending on the customer requirements. They cooperate with Clay Lacy Aviation for flying and Optech for the laser scanner. They target not only direct customers, but mainly also smaller surveying firms and governmental agencies who create and/or solicit for topographic maps and data but can not bear the high investment costs of ALS technology. They also offer consulting, and options to smaller companies and investors to participate in different forms in the commercialisation of lidar technology.

Australian Aerial Mapping Surveys (AAM) (S, L, CS) [Optech ALTM 1020]. 11 Wicklow St, Kangaroo Point, Queensland 4169, Australia, Tel./Fax: +61-7-38911033/3891 1050, qld@aamsurveys.com.au, www.aamsurveys.com.au/laser/. Contact: David Jonas. Firm is using the system of Geodan/ALI.

Eurosense Belfotop (S, L, CS) [Saab TopEye]. Nervierslaan 54, B-1780 Wemmel, Belgium, Tel./Fax: +32-2-4607000/4604958, info@Eurosense.be, www.eurosense.com. Contact: Dirk Fransaer.

Grontmij Geogroep (S, L, CS) [TopoSys I]. B&S Grontmij Geogroep, Stationsplein 13a, Postbus 1747, 4700 BS Roosendaal, The Netherlands, Tel./Fax: +31-165-568008/568018, www.grontmij.com.

Grontmij Geogroep provides services in co-operation with the firms TopoSys and Aerodata Int. Surveys. It has produced DEMs for Rijkswaterstaat, The Netherlands.

Hansa Luftbild (cooperates with TopScan) (S, L, CS) [Optech ALTM 1020]. Elbestrasse 5, D-48145 Münster, Germany, Tel./Fax: +49-251-23300/2330112, info@hansaluftbild.de, www.hansaluftbild.de. Contact: R. Schroth.

Hauts-Monts (S, L, CS) [Optech ALTM 1020]. Contact: Paul Smith, 3645, Ste-Anne Blvd., Beauport, Quebec, G1E 3L1, Canada, Tel./Fax: +1-800-4635611/+ 1-418-6674606, hauts-monts@hauts-monts.ca.

Intermap (S, L?, CS?). #900, 645-7th Ave. S.W., Calgary, Alberta, Canada T2P 4G8, Tel./Fax: +1-403-266 0900/265 0499, info@intermaptechnologies.com, www.intermap.ca. Contact: J. Bryan Mercer, bmercer@intermap.ca.

The company has performed first tests in combining their Star-3I interferometric SAR system with airborne laser scanning to derive bald earth DTMs in patchy thick vegetation areas.

Laser Mapping Specialists (S, L, CS) [Optech ALTM 1020]. Contact: Robbie Robison, 118 South Oak Street, P.O. Box 7, Raymond, MS 39154, USA, Tel./Fax: +1-601-8570796/8574181.

Precise Mapping (S, L, CS) [Optech ALTM 1020]. Contact: Richard Pollock, 12607-65 Avenue, Edmonton, AB, Canada T6H 1W7, Tel./Fax: +1-403-414-MAPS/437-5610, info@precisemap.com, www.precisemap.com.

PMI is the result of restructuring New-Tech Remote Sensing of Kamloops, British Columbia and pulling together additional owners and a new management team. PMI's main product, PreciseMap, provides terrain elevation and orthoimage map products. The original image footprint may be as small as 20 cm. The horizontal spacing of the laser points may be as small as 2 m. The absolute accuracy (in terms of average error) of horizontal and vertical positions taken from PreciseMap products is respectively 60 and 25 cm or better, depending on the characteristics of the scene. The base data is acquired from an aircraft equipped with the ALS and an integrated colour digital camera. Services: advanced multi-modal aerial remote sensing including digital imagery and laser-scanned DEMs.

Southern Applied Technologies (SAT) (S?) [AIMS 1000]. Contact: Robert H. Stokes, 1075 13th South Street, Birmingham, AL 35205, USA, Tel./Fax: +1-205-9345585/9756421.

The company had previously developed the AIMS 1000 ALS system (1994), marketed through SAT Leasing. SAT Leasing was later bought by ARM and this by Aerotec (see above). It is unknown whether SAT still provides ALS services. Services: major storm damage assessment, infrared and visual inspection, control of overhang wires, digital volumetric analysis, and mapping and profiling, specifically in gathering airborne survey data such as latitude, longitude, and elevation.

B.1.3.2. Bathymetric lasers.

Blom (S, L?, OS) [HawkEye]. Blom International is one of seven subsidiaries of Blom, a leading firm in surveying, mapping and information technology in Norway.

Blom International, Høybråtenvn. 13 b, N-1055 Oslo, Norway, Tel./Fax: +47-22-30-96-00/30-96-99, blom@blom.no. Contact: Terje Lund Henriksen, Managing Director, tlh@blom.no.

Blom International has different companies in Asia. One of them, Blom Dantarsa, is active in a large bathymetric project in Indonesia, using the HawkEye lidar hydrographic system from Sweden (probably leased from the Swedish Hydrographic Dept.). The DMRM Project (Digital Marine Resource Mapping of Indonesian Waters) was born from the Indonesian government's desire to adhere to internationally accepted standards while complying with the 1982 United Nations Convention on the Law of the Sea. This allows a state to declare itself as an Archipelagic Nation provided certain criteria are met. It also ratifies the concept of the EEZ (Exclusive Economic Zone). Under this concept, Archipelagic Nations possess sovereign rights to explore and exploit all the resources of the sea-bed, the subsoil and the water column out to a distance of 200 nautical miles from the baselines, which determine the Territorial Sea, the EEZ, the Contiguous Zone and the Continental Shelf. Out of the ca. 81,000 km of coastline, 46,000 km will be covered by airborne laser bathymetry which maps the shoreline as well as depths with a high degree of accuracy.

Blom Dantarsa, Jl. Kemang Raya 24, Jakarta 12730, Indonesia, Tel./Fax: +62-21-718-1633/719-4339, blom@blom.co.id, www.blom.co.id. Contact: Terje Lund Henriksen, Regional Director, tlh@blom.co.id.

Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALBTCX) (S, O, OS) [SHOALS (Scanning Hydrographic Operational Airborne Lidar Survey)]. JALBTCX, US Army Engineer District, Mobile, P.O. Box 2288, Mobile, AL 36628-0001, USA, general information, Tel.: +1-334-694 3721, Fax: +1-334-690 3464, shoals.sam.usace.army.mil/main.htm. Contact: W.J. Lillycrop, j.lillycrop@cerc.wes.army.mil.

Laser bathymetry was researched at the US Army Corps of Engineers in the 1970s and SHOALS is operational since 1994. It is used for general-purpose hydrography, monitoring of shoaling in navigation channels, coastal engineering studies of sediment transport, rapid response storm damage assessment. SHOALS has been previously used by the US Army Corps of Engineers for the US Government only, but is currently available world-wide for commercial use by governments and private companies. It was built by Optech and is operated by John E. Chance.

LADS Corporation Ltd. (S, O, OS) [LADS MkII (Laser Airborne Depth Sounder)]. Second Avenue, Technology Park, The Levels SA 5095, Australia, Tel./Fax: +61-8-83004447/83497528, lads2@vsl.com.au, www.vsl.com.au/lads/index.html.

LADS Corporation is a wholly owned subsidiary of Vision Systems. It was formed in February 1995 and has all LADS business responsibilities within the Vision Systems Group. It currently supplies maintenance and support under contract to the Royal Australian Navy LADS.

Terra Surveys (S, O, OS) [Larsen 500]. 2060 Walkley Road, Ottawa ON K1G 3P5, Canada, Tel./Fax: +1-613-731-9571/731-0453, terra@ottawa.terrasurveys.com, www.terrasurveys.com/. Contact: Kim Rossell, terra@sidney.terrasurveys.com, Tel./Fax: +1-250-656 0931/656 4604.

Larsen-500, 1983, world's first operational airborne laser hydrographic system, developed by Canadian Hydrographic Service, CCRS (Canada Center for Remote Sensing) and Optech. First CCRS system started in 1975. The firm also provides a separate airborne georeferenced (GPS/INS) imaging system employing video or digital cameras. Services: hydrography and coastal mapping.

B.1.4. Owners of ALS systems (possibly also providing services)

Environment Agency (Services too or only internal use?, O, CS) [Optech ALTM 1020]. Contact: Nick Holden, Rivett House, Lower Bristol House, Twerton, Bath, Avon, BA2 9ES, U.K., Tel./Fax: +44-1278-457-333/+44-1225-469-939, www.environment-agency.gov.uk/start.page.shtml. System used for flood mapping, coastal erosion, pollution control.

Eskom (Services too or only internal use?, O, CS) [Optech ALTM 1020]. Contact: Peter Moir, Megawatt Park, Sandton, P.O. Box 1091, Johannesburg, 2000, South Africa, Tel./Fax: +278-003-062/+278-005-160.

Kyushu Electric Power (O, OS using commercial laser from NEC or CS?).

Tokyo Electric Power (O, OS using commercial laser from NEC or CS?). Contact: Katsumi Ohhashi, t0742312@pmail.tepco.co.jp.

University of Florida, Geomatics (S?, O, CS) [Optech ALTM 1020]. Contact: Bill Carter, P.O. Box 116580, 345 Weil Hall, Gainsville, FL, 32611-6580, USA, Tel./Fax: +1-352-3925003/3923394, bcarter@ce.ufl.edu.

B.1.5. Consulting

Airborne Laser Mapping Consultants (ALMC). #2705-4 Forest Laneway, Toronto, Ontario, Canada

M2N 5X8, Tel./Fax: +1-416-225 8699/225 9947. Contact: Martin Flood, MartinFlood@csi.com.

ALMC offers professional consulting services related to all aspects of airborne laser mapping including system design, development and construction, multiple sensor integration, advanced technology analysis, industry market reviews, business case development, strategic planning and organisational issues related to deploying airborne laser mapping within a company. They are ideally positioned to act as facilitators for survey companies looking to acquire airborne laser technology but lacking in-house expertise to evaluate and review the various opportunities to implement this technology.

GeoLas Consulting. 2716 Farmington Drive, Alexandria, VA 22303, USA, Tel.: +1-301-286 3892, info@GeoLas.com, www.geolas.com. Contact: Christoph Hug.

GeoLas provides the following services: (a) technology consulting for imaging laser altimetry; (b) applications consulting for digital 3D landscapes and DSMs (application planning for 3D data users, visualisation support, application development for service providers); (c) algorithms and software development (filtering, data fusion and thematic analysis, modelling and visualisation); and (d) engineering support for airborne laser mapping systems (system concept and design, selection/integration/configuration of existing and development of custom software, lab and in-flight testing and calibration).

GeoLas does not offer laser survey services and is not affiliated with any service provider or system manufacturer.

B.2. Non-commercial and research ALS systems and some related projects

B.2.1. NASA related systems

The quality of NASA's WEB pages on airborne/spaceborne laser scanning seems to be inversely correlated to the scientific quality of its work. There is no comprehensive overview of NASA's activities in this field, many links do not exist, information is often outdated or very limited (e.g., just one picture for one system), there are multiple sites for single systems with overlapping but not identical information, etc. The major activities of NASA in this field are within the Laboratory for Terrestrial Physics (in its Laser RS Branch and in the Laser Altimeter Processing Facility of the Geodynamics Branch). The Wallops Flight Facility is also involved in other activities and especially projects.

B.2.1.1. Systems and missions.

Airborne systems

AOL (Airborne Oceanographic Lidar). In 1994 splitted to AOL (later AOLFL, FL = Fluorosensor) and ATM (Airborne Topographic Mapper). ATM-I since 1994, ATM-II 1996, ATM-III was under development in 1997.

ATM: aol.wff.nasa.gov/aoltm.html includes also information on ice mapping and beach mapping (coastal morphology) projects (see below). Contact: W. Krabill, krabill@osb.wff.nasa.gov.

RASCAL (RAster SCanning Airborne Laser altimeter). Since 1995, denali.gsfc.nasa.gov/sla/rascal/index.html. Contact: D. Harding, harding@denali.gsfc.nasa.gov, J. Bryan Blair, bryan@eib2.gsfc.nasa.gov.

SLICER (Scanning Lidar Imager of Canopies by Echo Recovery). Older system, not in development anymore, which was followed by LVIS.
ltpwww.gsfc.nasa.gov/eib/slicer.html, denali.gsfc.nasa.gov/sla/slicer/slicer.html. Contact: J. Bryan Blair, bryan@eib2.gsfc.nasa.gov, D. Harding, harding@denali.gsfc.nasa.gov.

LVIS (Laser Vegetation Imaging Sensor). LVIS used for validation of VCL data. NASA is trying to commercialise the system.
lvis.gsfc.nasa.gov/fmain.html. Contact: J. Bryan Blair, Tel./Fax: +1-301-286-9809/286-0213, bryan@eib2.gsfc.nasa.gov.

Spaceborne missions

MOLA (Mars Orbiter Laser Altimeter). MOLA-1 lost with spacecraft in 1993. MOLA-2 on Mars Global Surveyor, launched in November 1996, commenced continuous mapping of Mars on March 1, 1999. MOLA-2 has a range resolution of 37 cm, range precision of 2 m or better, a laser footprint of 130 m, along track spacing 330 m, across track spacing variable depending on mapping orbit and latitude, and an expected vertical accuracy of 10 m or better.

ltpwww.gsfc.nasa.gov/tharsis/mola.html. Contact: Dr. David E. Smith, +1-301-614 6020, dsmith@ltpsun.gsfc.nasa.gov.

SLA (Shuttle Laser Altimeter). SLA-01 in 1996, SLA-02 in 1998. SLA-01 is the first of four planned flights and measures backscatter from land surfaces, vegetation, ocean surfaces, and cloud-tops. The SLA has three primary objectives: (a) acquire samples of land topography and vegetation data, (b) provide an in-space engineering testbed for future space flight laser altimeter sensors, and (c) measure cloud and aerosol layers in the atmosphere. SLA-02, as SLA-01, is different than all laser altimeters that have flown in space previously because it records with a waveform digitiser the within-footprint character of each backscattered laser echo at up to 250 MHz bandwidth and most often at 100 MHz, i.e., is a true 'surface lidar' sensor. This allows to achieve within-footprint resolution of ca. 1.5 m (vertically) within each 100 m diameter footprint on the surface of the Earth. In those cases where unsaturated, multimodal echoes are recorded, it is possible to find the perceived ground portion of the return and separate it from the additional elements of vertical structure (buildings, trees, sand dunes, gullies, etc.) that may fall within the illuminated footprint. The objectives are to characterise the vertical roughness of as many different land cover classes and landscapes as possible on a global basis, and to focus attention on retrieving aspects of the relief of tree canopies under different conditions and in a broad variety of environments. In addition, SLA-02 measures cloud heights. Finally, SLA-02 seeks to continue the acquisition of geodetic quality surface elevation measurements, corrected for local slopes and vegetation heights in order to augment the SLA-based global database of ground control points. In order to accommodate the tremendous dynamic range of backscattered signal strengths observed with SLA-01 which was plagued by saturation, SLA-02 was modified to include a Variable Gain state Amplifier which will permit the SLA operator on the ground to control the signal intensity from the detector to the waveform digitizer to preclude saturation. SLA-02 will cover areas between 57° north and south latitudes. SLA-03 is planned as a small-footprint, ultra high pulse repetition rate version of SLA-02 to be launched in 1999. denali.gsfc.nasa.gov/research/laser/sla/sla1.html. Contact: Dr. Jim Garvin +1-301-2866565, garvin@denali.gsfc.nasa.gov, Dr. Jack Bufton +1-301-2868591, jbufton@ltpmail.gsfc.nasa.gov, Dr. David Harding +1-301-2864849, harding@denali.gsfc.nasa.gov, or Dr. Bryan Blair +1-301-2869809, bryan@eib1.gsfc.nasa.gov.

VCL (Vegetation Canopy Lidar) Mission, planned for August 2000. Satellite mission using the Multi-Beam Laser Altimeter (MBLA) lidar instrument. Instrument development based on SLA and MOLA (see above). The principal goal of the VCL mission is the characterisation of the 3D structure of the Earth. The two main science objectives are: (i) land-cover characterisation for (a) terrestrial ecosystem modelling, monitoring and prediction, and (b) climate modelling and prediction; (ii) global reference data set of topographic spot heights and transects.

The aim is to measure vegetation canopy top height with an accuracy of <1 m, the vertical distribution of intercepted surfaces, and terrain elevation with accuracy of <1 m in low slope terrain. The measurements will be used to create a variety of gridded and ungridded data products, including a high resolution grid of 2 km $\times$ 2 km and a low resolution grid of $1° \times 1°$. Important instrument parameters: Lasers: 3–5 Nd:YAG pulsed lasers, 1064 nm wavelength; pulse rate: 242 Hz; swath width: 8 km; laser footprint 25 m at 400 km altitude; track spacing: 2 km.
www.inform.umd.edu/Geography/vcl/(vcltext.html), ltpwww.gsfc.nasa.gov/division/VCLhome/, essp.gsfc.nasa.gov/vcl/. Contact: Dr. Bryan Blair +1-301-2869809, bryan@eib1.gsfc.nasa.gov.

GLAS (Geoscience Laser Altimeter System), planned for 2001. GLAS, an integral part of the EOS program, is a satellite laser altimeter, on board of ICESat, designed to measure ice-sheet topography and associated temporal changes, as well as cloud and atmospheric properties. Operation of GLAS over land and water will provide along-track topography. The laser will transmit 4 ns pulses of infrared light (1064 nm) and visible-green light (532 nm). The pulse rate will be 40 Hz, the laser footprint 70 m and the along track spacing 175 m. The infrared laser pulses will be used for ice sheet elevation and land topography and the green ones for the atmospheric measurements (detection of the small number of

photons backscattered from the atmosphere requires the use of photon-counting techniques that use visible-light detectors). The attitude-control system of the spacecraft will keep the laser-beam and telescope pointing toward Earth's center (nadir-direction) using information from star-trackers and GPS. Over most of the ice sheets, the accuracy of each elevation measurement will be 15 cm. Average ice elevation changes of less than 1 cm will be detected by averaging the elevation differences observed at many points in selected regions of the ice sheets. Over land, the vertical accuracy of the elevation measurements will be 0.5–1 m in regions of up to 10° slope and up to 10 m in regions of large slopes. Each measurement will represent the average surface elevation over the 70 m laser footprint. Surface roughness within the footprint will be derived from the widening of the return laser pulse. The primary purpose is (a) to determine the mass balance of the polar ice sheets and their contributions to global sea level change and (b) to obtain essential data for prediction of future changes in ice volume and sea-level. Secondary purposes are (a) to measure cloud heights and the vertical structure of clouds and aerosols in the atmosphere, (b) to map the topography of land surfaces, and (c) to measure roughness, reflectivity, vegetation heights, snow-cover, and sea-ice surface characteristics. The ICESat (Ice Cloud and land Elevation Satellite) is planned to be launched in July 2001, into a near polar orbit at an altitude of 600 km with an inclination of 94°.
ltpwww.gsfc.nasa.gov/eib/, glas.wff.nasa.gov/. Contact: Dr. James B. Abshire, jba@eib1.gsfc.nasa.gov (instrument team), Dr. Jack L. Bufton, jbufton@ltpmail.gsfc.nasa.gov (science team).

B.2.1.2. ALS related projects.

ALACE (Airborne LIDAR Assessment of Coastal Erosion). Co-operation of NOAA, USGS, NASA, flights from 96.
www.csc.noaa.gov/crs/ALACE/, coastal.er.usgs.gov/lidar/. Contact: W. Krabill, krabill@osb.wff.nasa.gov.

Beach mapping project (also called coastal morphology project). Co-operation of NOAA, USGS, NASA, NPS (National Park Service), flights from 95. aol.wff.nasa.gov/aoltm/projects/beachmap/, www.csc.noaa.gov/crs/beachmap/. Contact: W. Krabill, krabill@osb.wff.nasa.gov.

PARCA (Program for Arctic Regional Climate Assessment). NASA project initiated in 1995 to combine previous efforts at assessing whether airborne laser altimetry could be applied to measure ice-sheet thickness changes. The main goal is to measure and understand the mass balance of the Greenland ice sheet. The Arctic Ice Mapping (AIM) project of NASA is part of PARCA.

In 1991, NASA began an airborne program of laser altimetry combined with GPS and ring laser gyros to determine how accurately ice-surface elevations could be measured. By 1993, ice-surface elevations to a 10-cm accuracy level had been achieved. Flight-track repeatability, aided by the onboard GPS units, was about 50 m—well within the 150-m swath of the scanning laser. This ensured overlapping data swaths from repeat flights over the same routes, so that changes in ice-surface elevation during the interim between flights could be readily measured. In 1993/1994, NASA flew a network of flight lines that included all the major ice drainage basins on the Greenland Ice sheet. A repeat airborne survey of the 1993/1994 flight lines was planned for 1997/1998. Although spacing between adjacent flight lines was much larger than will be provided by GLAS, these measurements represent a baseline data set against which all future precise measurements can be compared. Thus, very soon after GLAS launch, it will be possible to provide first estimates of ice thickening/thinning for all major Greenland drainage basins.
aol.wff.nasa.gov/html/graphics_library/aoltm_science_data/icesheet.html, cires.colorado.edu/parca.html. Contact: W. Krabill, krabill@osb.wff.nasa.gov.

B.2.1.3. Other links.

LAPF (Laser Altimeter Processing Facility). Belongs to Geodynamics Branch of the Laboratory for Terrestrial Physics. Information on SLICER, RASCAL, SLA-1, SLA-2, ATM.
denali.gsfc.nasa.gov/research/laser. Contact: Dr. Jim Garvin +1-301-2866565, garvin@denali.gsfc.nasa.gov, Dr. David Harding +1-301-2864849, harding@denali.gsfc.nasa.gov.

Laser RS Branch. Belongs to Laboratory for Terrestrial Physics. Information on airborne and spaceborne earth observing lidars (GLAS, SLA-1 and -2, VCL) and lidars for extraterrestrial mapping and meteorologic applications.
ltpwww.gsfc.nasa.gov/eib/. Contact: James B. Abshire, Branch Head, jba@eib1.gsfc.nasa.gov.

B.2.2. Other systems and projects

ALII-3D (airborne 3D profilometer). Research project (1994–1995), funded mainly by the Technology Development Centre (TEKES), employing a photogrammetric method using a scannerless laser line and a CCD camera as detector, installed on a helicopter. The method was applied to the topographic measurement of ice fields. It is claimed that the new method will produce more reliable data on surface height and ice field mass than the previously used spot laser profilometer. The method will be developed with more effective laser and automation of the construction of profiles.
foto.hut.fi/research/projects/airborne_3d_profilometer.html. Contact: Henrik Haggrén, Inst. of Photogrammetry and Remote Sensing, Helsinki University of Technology, P.O. Box 1200, FIN-02015 HUT, Finland, Tel./Fax: +358-0-451-3900/465-077, Henrik.Haggren@hut.fi.

Coastal and Nearshore Mapping with Scanning Airborne Laser. USGS project dealing with mapping of coastal topography and bathymetry in cooperation with NASA, US Navy, NOAA, US Army Corps of Engineers and three university/research institutes. Three systems will be compared, namely SHOALS, LADS of the Naval Research Laboratory and NASA's ATM, whereby the first two systems can measure both bathymetry and topography.
coastal.er.usgs.gov/lidar/. Contact: Abby Sallenger, asallenger@cfcg.er.usgs.gov.

HawkEye (see also Blom above). Swedish hydrographic laser, since 1994, operational. Developed from FLASH (FOA Laser Airborne Sounder for Hydrography), main contractor SAAB Dynamics, main subcontractor Optech. Two versions, one for the Swedish Hydrographic Dept., the other for Swedish Navy. A third version was under development (1996) by Saab Dynamics and Optech. Helicopter-based, similar to SHOALS, but with real-time display of depth pattern and received laser waveform and different data processing. National Maritime Administration, Hydrographic Dept., Slottsgatan 82, S-601 78, Norrkoping, Sweden, Tel.: +46-11-19-10-00. Contact: Ulf Lejdebrink, Tel./Fax: +46-11-191077/133903, ulf.lejdebrink@ sjofartsverket.se.

LADS. Bathymetric and topographic airplane-based laser of the Naval Research Laboratory (NRL), USA. Previous Navy systems include PLADS (Pulsed Light Airborne Depth Sounder) in the 1970s and HALS (Hydrographic Airborne Laser Sounder), a prototype hydrographic system in 1986.
mp-www.nrl.navy.mil/marine_physics_branch/kgps.html. Contact: J. Brozena, Jr., john@hp8c.nrl.navy.mil.

LADS RAN. Bathymetric laser similar to LADS Mk II developed by Vision Systems and BHP Engineering from 1989 to 1993 for the Royal Australian Navy (RAN). RAN started laser bathymetry in 1975 with a profiler, and previous systems include WRE-LADS I and II. Maintenance and support currently supplied by LADS Corporation (see above) under contract to RAN. LADS RAN has surveyed nearly 34,200 km^2 in 4 years of operation. www.vsl.com.au/lads.

B.3. Web links

B.3.1. Bibliography

— w3.osa.org/standard/lidar96.htm: extensive bibliography since 1989, mainly for backscattering lidar;
— www.hydrosoc.demon.co.uk/subject/: references on hydrographic lidars, partly missing bibliographical information.
— shoals.sam.usace.army.mil/: SHOALS publications, not up-to-date, partly missing bibliographical information.

B.3.2. Tutorials

— aesd.larc.nasa.gov/GL/tutorial/tut_menu.htm;
— www.cord.org (very good course although information a bit old; WEB site under reconstruction; search for LEOT materials);
— bluegiant.phys.ksu.edu/vqm/laserweb/index.htm (broad scope but does not go into details);
— www.rli.com (different links including tutorials and a glossary);

— www.ilt.fhg.de / e / lasertutorial / lasertutorial.html;
— members.aol.com/wsrnet/;
— vcs.abdn.ac.uk/ENGINEERING/lasers/lasers.html;
— www.riegl.co.at/princip.htm;
— www.fas.org/man/dod-101/navy/docs/laser/fundamentals.htm.

B.3.3. Glossaries

— www.okisemi.com/communicator/public/nf/docs/LaserGlossary.html;
— optima-prec.com/notes.htm;
— www.kentek-laser.com/helpers/glossary.htm;
— www.laserfx.com: site for laser shows, but including useful information (glossary, bibliography, applications, links).

B.3.4. University research sites and public organisations

— www.ifp.uni-stuttgart.de/ifp/sensor/laser.html;
— www.nav.uni-stuttgart.de → Forschung → Jahresbericht 1997;
— www.geo.tudelft.nl/frs/laserscan/index.html;
— www.geod.ethz.ch/ggl/research/satnav.html;
— www.geog.nottingham.ac.uk;
— www.minvenw.nl/projects/airborn/coastmon.htm (coastal monitoring project at Rijkswaterstaat, The Netherlands);
— www.minvenw.nl/ahn (in Dutch, Rijkswaterstaat project for derivation of a nation-wide DEM).

B.3.5. Other links

— ourworld.compuserve.com/homepages/martinflood/: Reference site with extensive laser resources information, quite good, a bit N. America biased but improving lately;
— www.northcentral.tec.wi.us/programs/laser/LaserProfessional.htm (various links including a glossary and tutorial);
— www.geomatics.kth.se/~fotogram/OEEPE/oeepe_laser_main.htm: Working Group on Laser Data Acquisition of OEEPE (European Organisation of Experimental Photogrammetric Research);
— www.pacwest.net/byron13/sam/laserfil.htm and laserioi.htm (many links);
— www.lasertools.com/ (links, short glossary);
— www.achilles.net/~jtalbot/history/index.html;
— www.lfw.com: Optoelectronics World, on-line buyer's guides;
— www.geocities.com/CapeCanaveral/Lab/3931/: Laser resource library;
— www.ieee.org/organizations/society/leos/: IEEE Lasers and Electro-Optics Society.

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