International Hydrographic Review, Monaco, LXV(2), July 1988

NEW CHARTING TECHNOLOGY IN AUSTRALIA : THE LASER AIRBORNE DEPTH SOUNDER

by Commodore J.S. COMPTON, RAN (*)
and Lt. Cdr. M.A. HUDSON, RAN (**)

Paper originally presented at the IXth Congress of the International Maritime Pilots Association held at Melbourne, Australia, in February 1988 and reprinted with the kind permission of the Congress' organizers.

BACKGROUND

Australia's area of charting responsibility covers some 11.5 million square nautical miles of ocean and sea area. In general terms it extends from the middle of the Indian Ocean to the mid Tasman Sea and from the Antarctic to the northern areas of Papua New Guinea. Of primary concern, however, is the continental shelf area (some 660,000 square nautical miles) of which, to date, only about 40% has been surveyed to either acceptable or temporarily acceptable standards. The task of completing this priority area with existing RAN Hydrographic Units has been estimated to take another 40 to 50 years.

The importance of accurate and comprehensive hydrographic data to naval, commercial and recreational users of our oceans has long been recognized. In the early 1970s, the RAN Hydrographic Service, as part of its endeavours to speed up the surveying programme, requested the Defence Scientific and Technology Organization Laboratories at Salisbury, South Australia, to investigate the use of an airborne laser sensor to measure water depths.

SYSTEM DEVELOPMENT

Trials were conducted over several years to determine the feasibility of the Laser Airborne Depth Sounder (LADS) concept, and to ensure that it would meet

(*) Hydrographer, Royal Australian Navy Hydrographic Service, P.O.Box 1332, North Sydney, NSW 2060, Australia.
(**) Systems Manager, Laser Airborne Depth Sounder Project.

the requirements of the hydrographer. Initial trials involved mounting the laser, which was known as WRELADS 1, in a Queenair Beechcraft aircraft. This configuration was operated for 150 hours, sampling data in South Australian and Queensland waters to test the potential for reliable depth measurement and laser operation.

Following the success of WRELADS 1, a more advanced system, WRELADS 2, was developed and fitted in an RAAF C47 aircraft. This configuration included a precise navigation system, ARGO DM54, which is currently the standard long range position fixing system in RAN hydrographic ships. A swathe sounding capability was also introduced. Trials were conducted in South Australian, Queensland and West Australian coastal waters. Some 500 hours on task time were achieved, culminating with a survey off Fremantle, W.A., covering an area of 3 km × 30 km. This survey was completed in a single 4 hour sortie with a data success rate of over 95% and depths over 50 m were measured.

With trials completed, a Project Definition study was carried out with the assistance of industry, to develop the proven concepts and produce documentation which would allow industry to construct a LADS system. At present, this production data package is with twelve potential prime contractors and a contract to build an operational system should be signed in the latter part of 1988. The LADS conventional integration concept is shown in Figure 1.

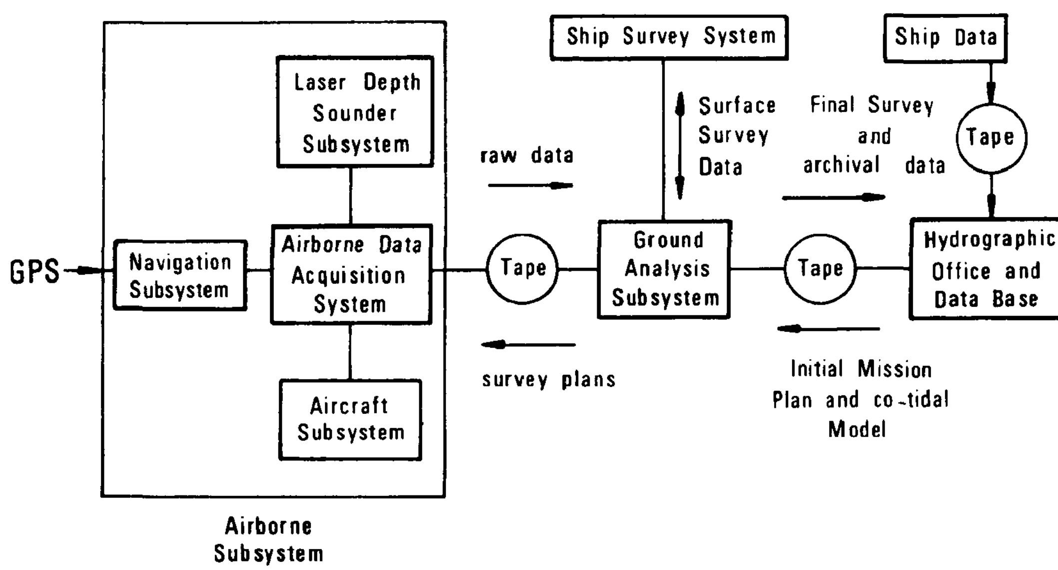

FIG. 1. — LADS Scheme Integration and Concept.

SYSTEM CONFIGURATION AND CHARACTERISTICS

General Overview

In essence, the LADS system will consist of a stabilised laser and associated navigation and data logging units mounted in a Fokker F27 aircraft; and a Ground Analysis Subsystem (GASS) fitted in a mobile trailer to be located at each operational site. The laser emits green and infra-red pulses at a rate of 168 per second, the green being reflected from the sea floor and the red from the sea surface. By accurately measuring the time difference between the two reflections, depth can be obtained. Tidal adjustments and position are related to individual depths by time. The system is designed to operate in shallow continental shelf waters in day and night conditions and to measure water depths in the range 2 to 50 metres (the maximum depth is dependent on water turbidity).

The aircraft will fly preplanned tracks over the area to be surveyed at an altitude of 500 metres and a speed of 70 metres per second (approximately 140 knots). Under these flying conditions, LADS will record depth soundings spaced 10 metres apart in a rectangular pattern 240 metres wide. This equates to an area coverage of 17,000 square metres per second of flight time.

Major Subsystems

LADS consists of an F27 aircraft configured to meet the laser sounding task and four major subsystems.

Aircraft Subsystem (ASS)

The aircraft subsystem consists of the required modifications to the aircraft structures and systems necessary to support the operation of the LADS airborne equipments. These include:

a. Provision of a fuselage-mounted glass window and equipment bay to allow the transmission of laser signals to the ocean below and to provide a field of view for a television camera;

b. Provision of electrical power and cooling to the LADS airborne equipment;

c. Provision of inter-communication links and interface equipment, and

d. Provision of various crew and safety items.

Laser Depth Sounder Subsystem (LDSS)

The LDSS (Fig. 2) is designed to perform the following functions:

a. Generate green and infra-red laser pulses and direct these to the sea surface via a scanning system capable of producing, when combined with the aircraft forward motion, a rectangular scanning pattern at the sea surface;

b. Receive the returns from the sea surface and bottom and amplify the signals to a usable level;

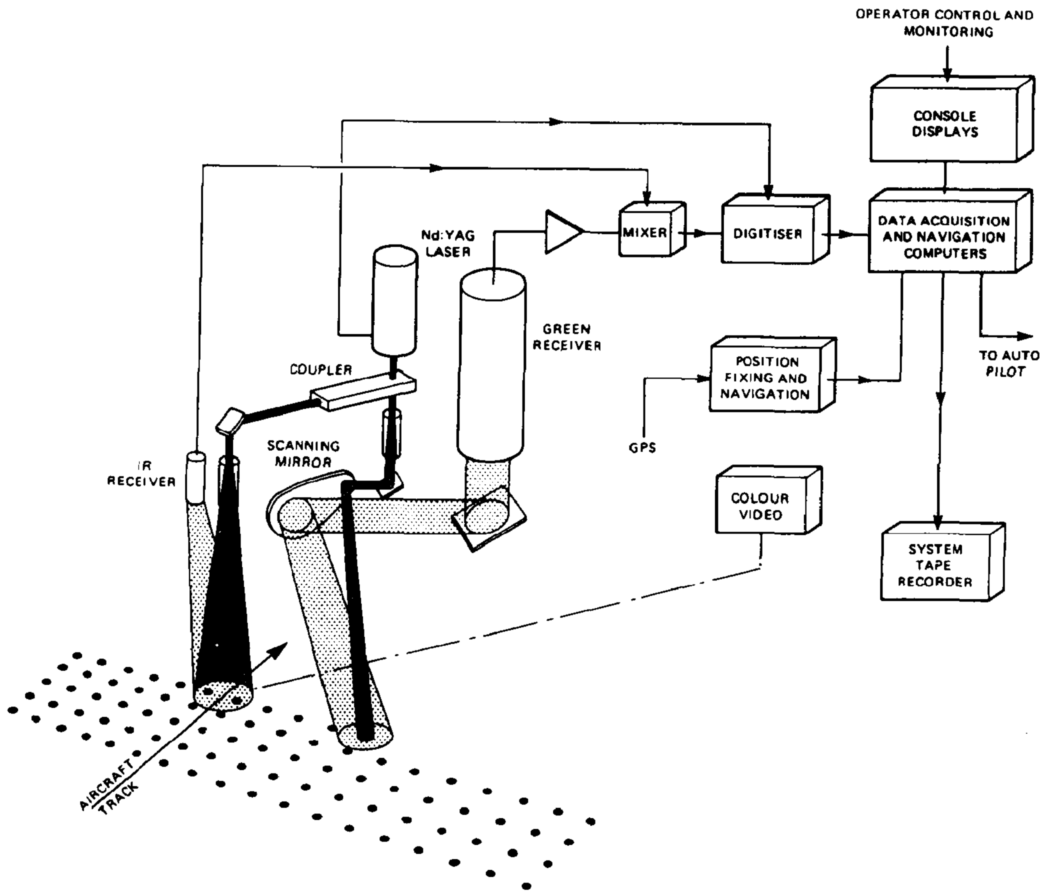

FIG. 2. — Laser Depth Sounder Subsystem.

c. Provide a stabilised platform for the laser transmission and receiving equipment (pitch +6° to +1°, roll ±5°, drift angle ±20°);

d. Provide a downward looking video camera on the stabilised platform.

Airborne Data Acquisition Subsystem (ADAS)

The major functions of the ADAS (Fig. 3) are to:

a. Acquire and record position and depth information collected from the GPS navigation system and LDSS.

b. Allow the operator computer control of the airborne equipments and survey objectives with operator monitoring and interrupt facilities.

c. Determine the aircraft position and compare with the position requirements of the sortie plan; provide navigation correction signals to the aircraft autopilot and/or provide specialised navigation information to the pilot for manual flying.

d. Provide a colour television monitor system to allow the operators to view

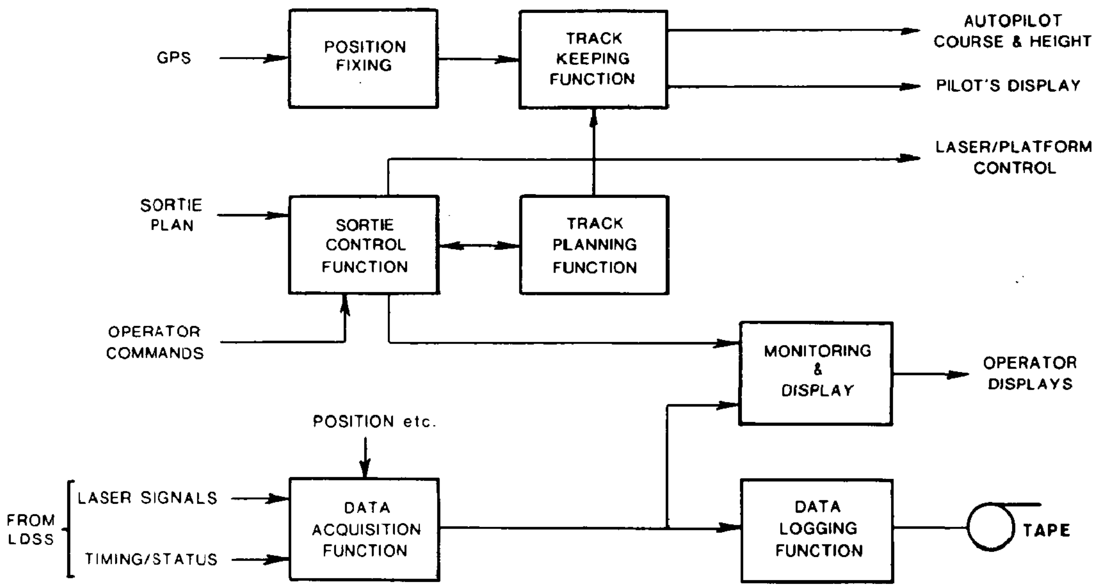

FIG. 3. — ADAS Functions.

the sea surface. Graticule and system data will be generated and added to the composite video signal which is viewed by the operators and recorded on the video recorder. The potential for inclusion of a multi-spectral scanner (MSS) exists.

Ground Analysis Subsystem (GASS)

The GASS (Fig. 4) is a field transportable, computer based processing system which accepts raw data on magnetic media from the ADAS, tidal data and the mission plan to produce both archival data reduced in density for the Hydrographic Information System (HIS), In addition, the GASS will provide facilities to assist the hydrographic surveyor in the planning and review of the mission and individual sorties. The sortie data will be processed and presented for review one day after collection, so that assessment can be considered in the continuing survey planning activity.

The main functions of the GASS are to:

a. Determine depth and position of soundings;

b. Reduce, select and validate soundings;

c. Plan and review mission activities.

System Accuracy

LADS is designed to achieve accuracies of at least:

a. *Depths:* over the range of water depths from 2 to 30 metres within 1.0 metre. Accuracies beyond 30 metres are yet to be determined.

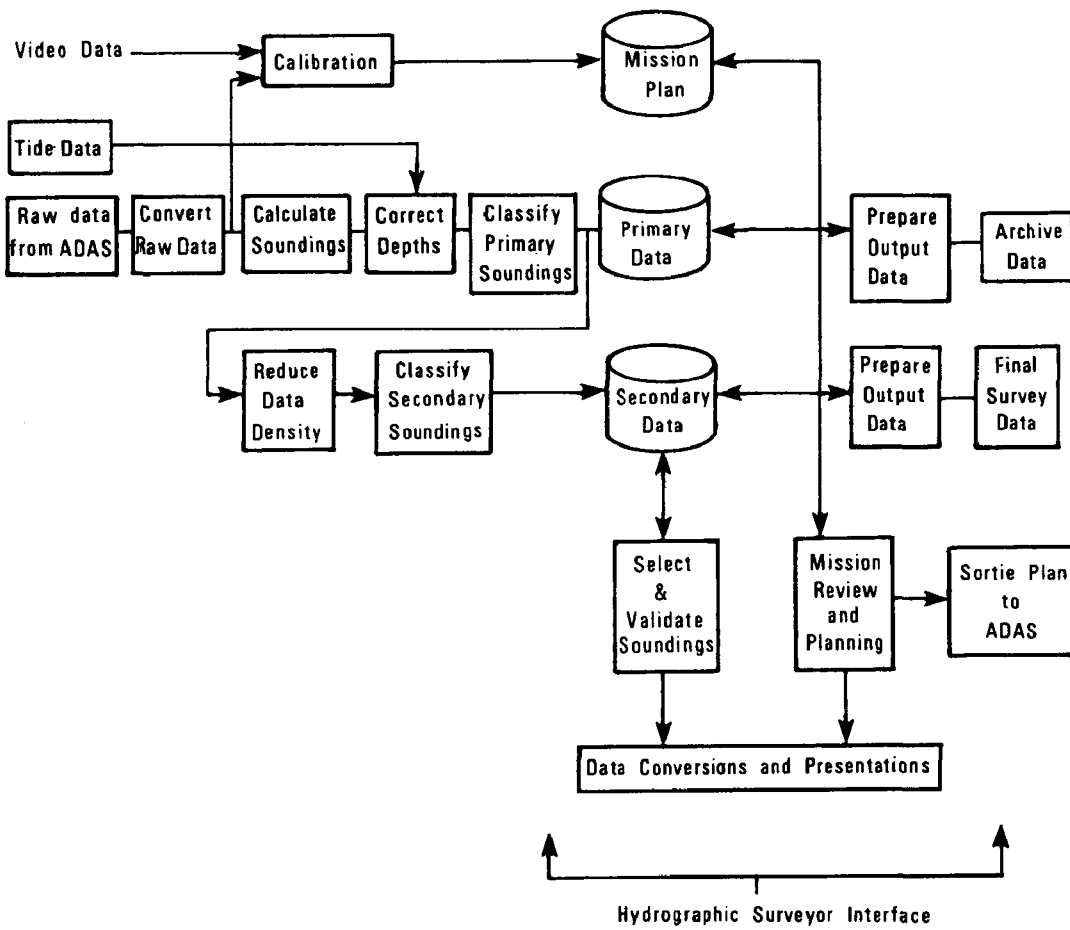

FIG. 4. — Ground Analysis Subsystem.

b. *Position:* to a resolution of 1 metre with an accuracy of 15 metres.

This is derived from two requirements:

(i) Aircraft position determined to 14 metres using a GPS navigation system, and

(ii) The position of all soundings of less than 30 metres relative to the optical platform to 5 metres.

c. The nominal pattern of soundings at the sea surface consists of rows of green pulses, transverse to the track of the aircraft, centred either side of the aircraft vertical, with a mean spacing of 11.25 metres between pulses. (The first and last soundings in each row are analysed to determine optical parameters of the water for validation and update of the bias model, limiting depth determination to the 22 intermediate soundings.) Rows of soundings are repeated at a spacing of 10 metres along the aircraft track. The accuracy of the position of these soundings, within a pair of adjacent scans, is less than ±2 metres of the nominal position.

d. A time base to relate position, depths, tide and video data will be provided to a resolution of 10 milliseconds.

In practice, depth and positional accuracies have been demonstrated to be well within these figures; typically ±0.3 metre in depth and 11 metres for position.

Personnel

LADS will be a unique unit in the RAN. Apart from system operators, all logistic support will be provided by contractor. The RAN Hydrographic Service will crew LADS with one Lieutenant Commander (Charge Surveyor and OIC), two Lieutenants (Assistant Surveyors — survey flight coordinators), two Petty Officers (Senior Survey Technicians — survey flight operators) and one Leading Seaman (Junior Survey Technician — administrative support and tidal data coordinator). RAN personnel will be based from the Hydrographic Office in Sydney.

Contractor personnel will fly the aircraft, maintain all LADS systems and the aircraft, arrange all logistic support in the operating areas and provide most of the operator training for RAN personnel.

System Limitations

Although the system is capable of detecting depths in excess of 50 metres, this is dependent on water clarity. Areas of high turbidity will significantly degrade LADS performance and need to be identified as part of the survey planning process. In addition, high sun angles and sea states will degrade LADS operations. (High sun angles cause unwanted reflections of sunlight into the laser receiver.) Rough seas present problems by increasing water turbidity. Low cloud, rain and strong winds provide obvious difficulties for both the laser system and aircraft operations.

Laser Safety

Considerable effort has gone into ensuring that the laser presents no danger to either the air crew or others on the ground or in vessels overflown during survey operations. Laser safety aspects have been reviewed by the Australian Ordnance Council and measures to safeguard personnel include:

a. Tailoring laser power to ensure that the system is inherently safe to the public,

b. As a backup to *(a)*, operating procedures which require the system to be inhibited when overflying land or ships, and

c. Laser safety courses for all operators.

DATA ACQUISITION AND ANALYSIS

As indicated above, raw data in the form of position, time and depth are obtained via the GPS and LDSS. The logging, control and monitoring of this data are carried out by the ADAS as dictated by the hydrographic survey crew.

Acquisition

The laser consists of a neodymium doped yttrium aluminum garnet (Nd:YAG). This is Q switched to produce short duration output pulses at the rate of 168 per second. The laser transmits simultaneously short pulses of infra-red (1064 nanometres giving a spot of 25 metres diameter on the sea surface) and green (532 nanometres giving a spot of 1.5 metre diameter on the sea surface). The vertically stabilised infra-red (IR) beam is used to establish a reliable sea surface datum and the green beam is scanned across the aircraft track to obtain bottom reflections (Fig. 5). The surface model is calibrated through the green beam reflections from the surface, averaging according to beam inclinations and surface roughness. The laser 'nods' through an arc of ±15 degrees about the vertical, while rotating along the axis of the aircraft to produce the rectangular sounding pattern.

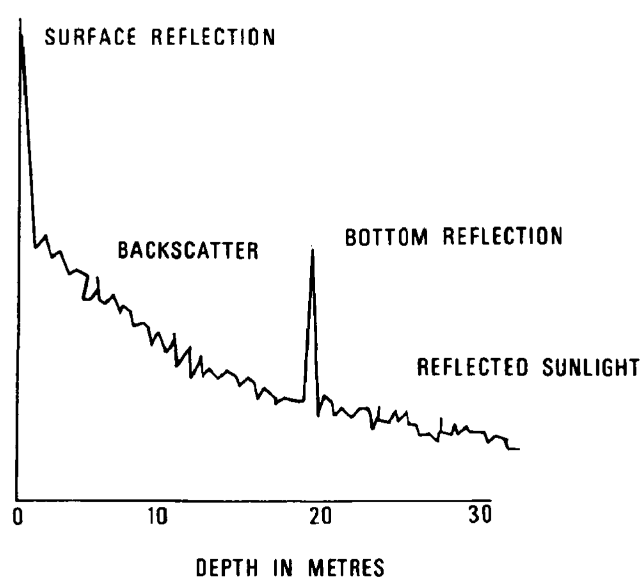

FIG. 5. — LADS Received Waveform.

Variations in the nature of the bottom will result in differing quality of the return pulses. In general, hard smooth bottoms will provide the best return, while areas of thick weed, soft mud and other poorly defined surfaces will degrade bottom reflections. In very shallow water, the problem is to identify the bottom among the surface reflections, hence a 2 metre minimum depth. Variations in salinity and temperature have minimal effect on system performance. Practical effects of this minimum depth can be overcome in most areas by 'working the tide'.

Received IR and green pulses are amplified and digitized to a 6-bit accuracy by a Biomation waveform recorder at 2-ns intervals corresponding to a depth increment of 0.22 metre. Between laser transmissions, the waveform data is read out of memory using the IR surface reflection pulse as the principal timing reference. During this process, a timing correction is applied to account for the additional distance travelled by the green pulse to reach the sea surface compared with the IR reference pulse. After this, the waveform (raw depth data) is recorded within the ADAS and tagged with position and time.

Analysis

All analysis of data is carried out on the ground in the GASS. In overview, the system carries out raw data processing, calculates soundings, corrects depth for tide, classifies these primary soundings to primary data and stores, reduces the density of the data to a chosen survey scale, classifies this secondary data and then stores it. The GASS also has the function of planning subsequent survey sorties for transfer to the ADAS in digital form on disc (see Fig. 4).

Raw Data Processing

This process unpacks and scales the data logged by the ADAS on tape and stores it in the GASS data base. Additionally, the converted raw data is analysed for initial error conditions such as discontinuities in the data and error flags set.

Calculation of Soundings

This function converts raw position and waveform data to soundings comprising position, depth and confidence vector. The position is expressed in geographics. The depths calculated from the raw digitized waveform are corrected for system geometry and depth bias errors.

a. Corrections for system geometry are a function of the scan angle, aircraft height, angles of the stabilised laser platform and aircraft heading.

b. Depth bias is generated because individual light photons follow different paths in water. It is a function of sea depth, angle of the incident beam to the local vertical, turbidity and surface roughness. A bias model has been developed from analysis of the trials data to correct for depth bias.

Confidence vectors for position and depth are applied to each sounding. These are a measure of the expected reliability of depth and position based on factors such as known turbidity, correlation between adjacent soundings, quality of the surface reflection reference, strength of the reflected pulse and position confidence gleaned from satellite fix data.

Depth Correction for Tide

This function corrects observed sounding for tide using a choice of tidal models within the GASS. These are two prediction models (Institute of Ocean Sciences model — for areas with comprehensive existing tidal data and the Admiralty model — for areas with limited tidal data) and a cotidal model with range factors and time differences. Tidal monitor stations will be established in the survey area to provide data and the aircraft position in relation to the station/s calculated to allow a height of tide to be obtained at the point of sounding. Initially, observed tidal data from the monitor station will be manually input.

Classification of Primary Soundings

All primary data is reviewed. Tracks actually flown are compared with that planned, soundings are classified by confidence vectors and the performance analysed.

Reduction to Secondary Data

Primary data is reduced on a swathe by swathe basis to a density determined by scale. In conjunction with this process, the secondary soundings are reclassified with confidence vectors based on agreement with adjacent primary soundings, agreement with chosen secondary points, gradient of secondary points and the number of primary points in a given area around the secondary point that met acceptance criteria for the primary point data.

Classification of Secondary Data

This process classifies each of the secondary soundings according to its acceptability as final survey data. The classification defines the confidence vector of each depth in terms of its agreement with adjacent soundings and includes confidence data from the adjacent original primary data.

All the above processes are carried out 'hands off' apart from basic control commands. The hydrographic surveyor then has access to the system to select and validate soundings interactively. The operator has the facility to change the secondary depth values, select and/or delete secondary data and apply depth datum shifts for accepted data under controlled circumstances. The validation process also allows the operator to produce sortie maps, reports and sort data for resurvey by either the aircraft or ship. The GASS also carries out comparisons between ship benchmark surveys and LADS calibration runs.

OPERATIONAL SCENARIO

General Outline

LADS will deploy for three 90 day missions per year and in general be utilized for survey tasks in the northern areas of Australia. A hydrographic vessel will be provided in support of each survey to assist in obtaining tidal data, conducting benchmark surveys to calibrate LADS, investigate areas of interest identified by LADS and assist in establishing navigation check points for the LADS Global Positioning System (GPS).

Hydrographic data gathered by LADS during the course of a sortie will be processed in the GASS based at the operating airfield. This analysis task will reduce the mass of primary data to a form more suitable for inclusion in the Hydrographic Office data base and subsequent chart production. Data will be transmitted to the Hydrographic Office on a regular basis by magnetic tape medium.

Example Mission

In a typical 90 day mission there are five main phases:

a. Planning of mission activities including such points as:

i. defining the area to be surveyed including areas of particular interest,
ii. identifying suitable navigation check points,
iii. researching tidal data and identifying locations for tidal stations,
iv. arranging logistic support, and
v. developing an outline survey plan.

b. Deployment of all LADS equipment, personnel and the aircraft to the operating area.

c. Establishment of the various equipment and personnel elements in the operating area including preliminary calibration and reconnaissance flights. If required, a navigation monitor station will be located within the survey area. This station will monitor pseudo range and time errors in the GPS.

d. Flying of survey sorties, analysis of data and investigations by the support vessel.

e. Pack up and return to base area.

It is expected that initially most LADS missions will be directed at the north west, north and north east coasts of Australia operating from airfields such as Broome, Darwin, Wiepa and Townsville. Individual sorties may take place up to 300 nm away from the operating airfield.

Example Sortie

During the course of a typical mission, approximately fifty individual survey sorties (see Fig. 6) will be flown of up to seven hours duration each. Sortie planning will take into account the tide, weather and water turbidity. In certain circumstances, night flying will be undertaken to extend system performance.

Planning Phase

Much of the sortie plan will be developed on the GASS. In this process each objective of the flight is programmed and each survey run detailed. Although the survey plan can be modified in flight, unforeseen circumstances

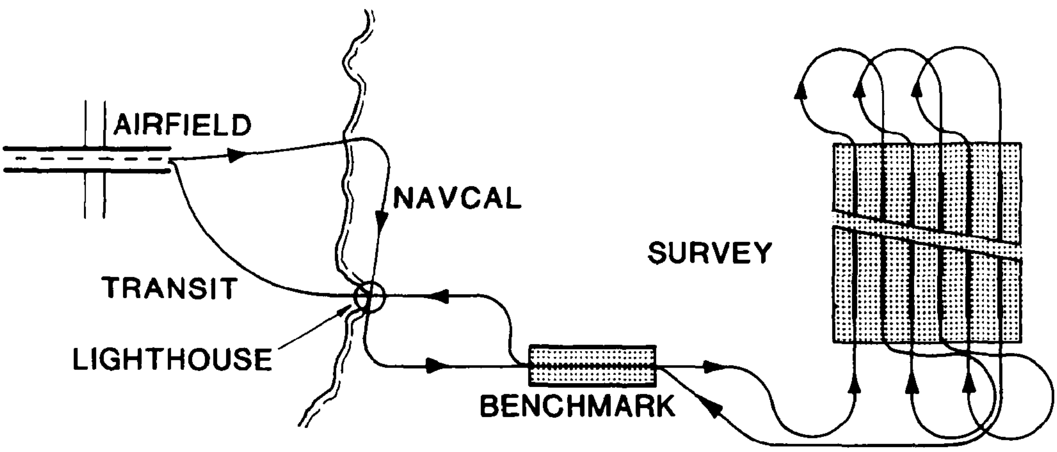

FIG. 6. — LADS Sortie.

and/or poor conditions in the chosen sortie area will normally be dealt with by changing to an alternative flight plan in toto. The survey plan will include all navigation check points, a calibration run at the beginning and end of sortie and the start and end coordinates of each sounding run. Each run will be tagged with its own discrete number. Clearance of the flight plan with the civilian airfield authorities will be the responsibility of the contract pilots according to normal Department of Aviation regulations.

Briefings

Survey and general flight briefings will be carried out by the air crew and senior surveyor prior to each sortie.

Survey Flight

Each sortie may last for up to seven hours including the transit time. The maximum radius of operations is 600 km and at that range a sortie would involve three hours transit and four hours on task. After take off and before surveying starts, a navigation check is carried out by overflying a previously coordinated and well defined point. This will be recorded by the bore sighted video camera to ensure the accuracy of GPS. Once in the survey area, a calibration run will be carried out over a previously surveyed area to check the accuracy of depth measurements. In addition, the results will be used to set a depth calibration confidence qualifier for the sortie and refine the bias correction for the data conversion model. To obtain the best results from GPS, sounding runs will be as long as possible and turns kept to a minimum.

Processing

Processing of the data has already been described. In terms of its operational significance, however, it is important that data is analysed as quickly as possible after each sortie and, as a target, all processing should be completed within 24 hours.

CURRENT STATUS OF SYSTEM

The Request For Tender to build a fully operational LADS system is currently with Australian industry. A production contract is expected to be signed in the second half of 1988 and flying trials commence in early 1990. The RAN Hydrographic Service expects to accept LADS into service in mid 1991.

CONCLUSION

LADS is as significant an event in the development of hydrographic surveying as the echosounder. Although there will always be the need for a ship 'on the ground' to investigate sounding profile anomalies, conduct deeper water surveys and provide general survey support, many previously inaccessible areas, such as reef strewn waters, can now be surveyed in relative safety at great speed.

REFERENCES

[1] Laser Airborne Depth Sounder System Production Data Package. Various authors. Department of Defence (Navy) and DSTO Laboratories Salisbury, S.A. (Surveillance Research Laboratory).

[2] Airborne Laser Hydrography in Australia, 1985. M.F. PENNY, R.H. ABBOT, D.M. PHILLIPS, B.BILLARD, D. REES, D.W. FAULKNER, D.G. CARTWRIGHT, B. WOODCOCK, G.J. PERRY, P.J. WILSEN, T.R. ADAMS and J. RICHARDS.

[3] Applied Optics, Volume 25, No. 13, 1 July 1986. A collection of seven papers covering Australia's R&D Programme in Laser Hydrography.

[4] Discussions with Mr M.F. PENNY, Technical Manager, Laser Airborne Depth Sounder Project Technical Cell (DSTO Laboratories Salisbury, S.A.)