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ROYAL AUSTRALIAN NAVY LASER AIRBORNE DEPTH SOUNDER, THE FIRST YEAR OF OPERATIONS

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Abstract

The Laser Airborne Depth Sounder (LADS) has been a longstanding research and development project with the Royal Australian Navy. Following Defence Acceptance Trials the system was provisionally accepted into service and commenced operational surveys in north Queensland in March 1993. The majority of the year saw LADS surveying in the Flinders Passage area from operational bases in Townsville and later Cairns. During that period a number of enhancements were implemented and LADS was formally accepted into naval service on 8th October. In November a new survey was commenced between Fairway Channel and Bunker Reef, about 200 nautical miles north of Cairns. After dealing briefly with the history of development, this paper will concentrate on the operational and surveying aspects of LADS' first year, and comment on the direction of further development.

INTRODUCTION

The concept of collecting hydrographic data by using laser pulses from an aircraft was proven in the late 1960s at Syracuse University Research Corporation [2]. Its first demonstration in Australia was in 1974 during trials of a laser terrain profiling system developed by the Defence Science and Technology Organisation (DSTO) at Salisbury, South Australia. Following an expression of interest from the Hydrographer, two experimental systems were built and tested between 1976 and 1984. The second, WRELADS II, incorporating a scanning system and precise navigation receiver, completed over 550 hours of test flying over seas off South Australia, Queensland and Western Australia. Using the lessons learned from these

[1] Royal Australian Navy.

[2] HICKMAN, G.D. & HOGG, J.E. 1969, Application of Airborne Pulsed Laser for Nearshore Bathymetric Measurements. *Remote Sensing of the Environment 1*, p. 47-58.

trials to enhance some of the design aspects of WRELADS II, an engineering production package was developed and a contract awarded in 1989 for the production of a single system for operational use by the RAN Hydrographic Service.

Throughout the production phase the Commonwealth Project Authority, having specified the algorithms and corrections by which to reduce waveform information to soundings, retained responsibility for the accuracy performance of LADS. The contractor, BHP(Engineering) in association with Vision Systems, took on the remaining responsibilities including functionality and reliability. The production phase culminated in a series of trials in which the contractor demonstrated compliance with the requirements of the build and test contract and LADS achieved contractual acceptance on 29th January 1993.

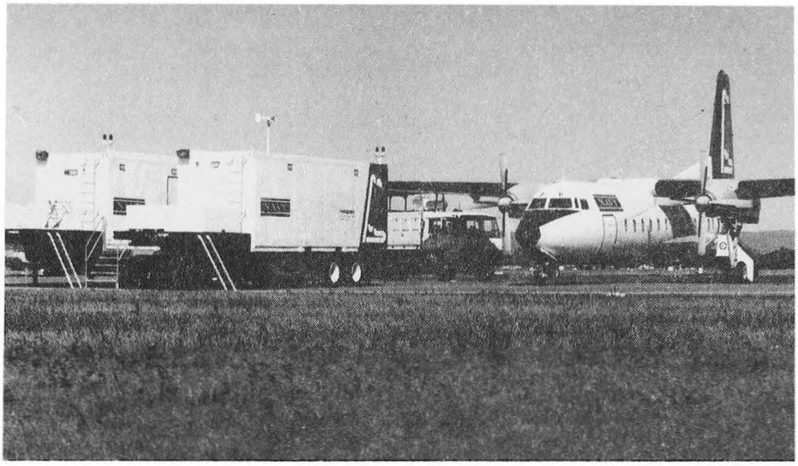

FIG. 1.- LADS aircraft and ground equipment.

DEFENCE TRIALS - SPENCER GULF, SOUTH AUSTRALIA

A two week Defence Trials period of intensive hydrographic surveying operations followed immediately from contractual acceptance. These trials were the first opportunity for Navy operators to take full control of the system and were intended to test the operational limitations of the system and identify any critical shortcomings. Ten sorties totalling 53 hours were flown within 12 days in difficult environmental conditions with ambient temperatures reaching 42 degrees Celsius. During the trials LADS discovered an isolated, uncharted shoal of dimensions 60 metres by 20 metres, rising to 11.9 metres out of general depths of 20 metres. The shoal, initially referred to as "Laser Shoal", was later officially named "Penny Shoal", in recognition of the significant contribution to the development of LADS made by Mr Mike Penny, the principal DSTO scientist on the project. Penny Shoal is of great navigational significance, lying within a mile of the busy harbour approach to Port Lincoln, which is regularly used by bulk wheat carriers with draughts of up to 14 metres. More importantly to the Charge Surveyor were the depth, position and detection repeatability shown on 4 independent passes over the rock on three different days. The results, tabulated below, provided the perfect confidence check on a totally new system about to embark on its first operational survey.

Depth	Date	Time(z)	Track	Easting	Northing	Tide Corr. (included)	GPS (EHE) (metres)
12.1	09 Feb	1031	270°	600 889	6 158 050	0.28	7
12.1	09 Feb	1042	090°	600 885	6 158 046	0.23	7
12.1	11 Feb	0805	000°	600 877	6 158 057	0.76	12
11.9	12 Feb	1013	000°	600 881	6 158 048	1.07	7

The original survey of the area was conducted in 1966 by conventional acoustic echo sounder with no sonar sweep. The main lines were sounded in an east-west direction at a spacing of 200 yards and Penny Shoal, also aligned east-west, plotted mid-way between the lines. The discovery highlights the inadequacy of unswept acoustic surveys in shallow water and the superior ability of LADS to detect such isolated features.

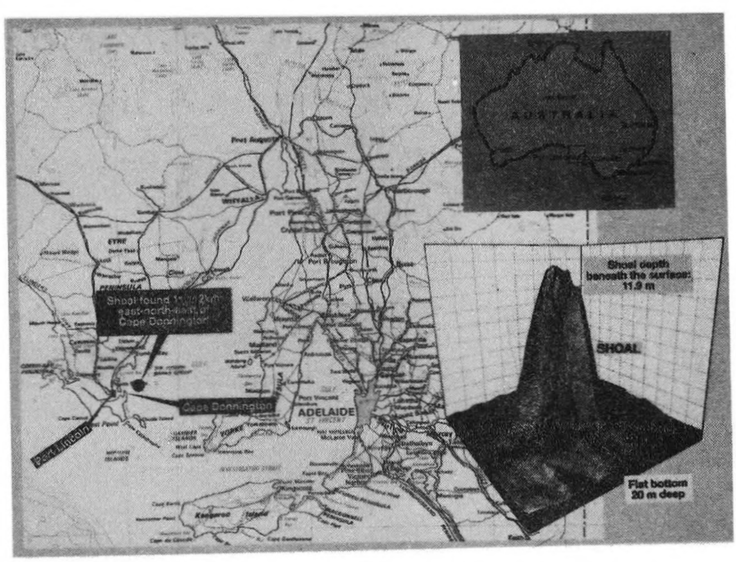

FIG. 2.- Laser shoal/Port Lincoln.

Other outputs of the Defence Trials period were the identification of a number of LADS' shortcomings and the characterisation of laser waveforms received from schools of fish. The fish contacts, which proved to be from schools of pilchards, were surprisingly convincing at first look, but close investigation showed a characteristic distortion on the leading edge of the returned laser waveform and a lack of supporting returns from depths between the school and the true seabed. These schools were easily disproved by reflying the positions. The shortcomings of the system mainly related to data validation and operator useability such as; lack of software traps to remove "afterpulses" [3] and "infra-red dropouts" [4]. After agreeing on a rectification schedule, LADS was provisionally accepted into operational service and the complete system was deployed to Townsville to commence the Flinders Passage survey in March 1993. The LADS operational base was moved to Cairns at the beginning of June, however routine sorties to Flinders Passage continued until the end of October.

FLINDERS PASSAGE SURVEY - HYDROGRAPHIC INSTRUCTION 185

Aim

The aim of the Flinders Passage survey was to prove a deep draught shipping route between the Great Barrier Reef inner route (in the vicinity of Abbot Point) and the Coral Sea. An important ancillary aim was to compare the results of LADS with those of conventional survey ships and to this end two Survey Motor Launches were tasked to survey some of the same area. The LADS survey area was defined by a rectangle of approximate dimensions 60 by 36 nautical miles, however, confirmation of shoals on the north-eastern survey limit and the charted indication of shoals near the northern approaches to the proposed recommended routes necessitated the extension of the survey area in that direction. Throughout the area, which was previously unsurveyed, numerous drying and submerged reefs rose steeply from a generally flat seabed. Between the reefs general depths were about 35 metres at the inshore survey limit and in excess of 50 metres offshore.

Operational Aspects

Six RAN personnel, headed by a Lieutenant Commander, Charge Surveyor make up the LADS Unit and carry out all collection and processing of survey data. Operational and logistic support is provided under one operational support contract. The contractor employs 7 personnel in the field to meet his commitments, they include:

- Field Manager (1)
- Pilots (2)
- Aircraft mechanics (2)
- Airborne System Maintainer (1) and
- Ground System Maintainer (1).

[3] An "afterpulse" is a characteristic of high gain photomultiplier tubes, a false signal generated by the tube itself. An afterpulse is usually identifiable by its high height to width ratio.

[4] "Infra-red dropouts" are the failure of a return infra-red signal to be detected which causes a loss of timing of the returned green laser waveform.

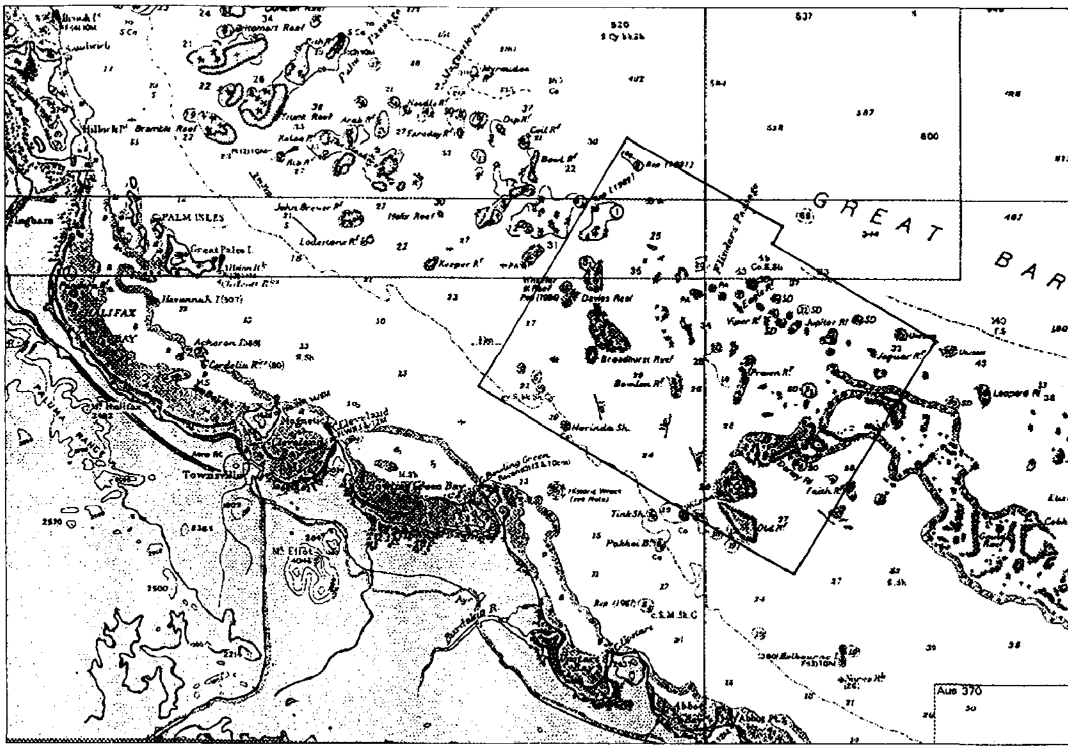

FIG. 3.- Flinders Passage survey area.

In addition, a small technical support team is located at the maintenance base.

Normal operations consisted of afternoon / evening sorties [5] of about 7-7.5 hours duration and 4.5 - 5 hours data collection at a rate of 7 sorties per fortnight. The overall limitation on sortie duration is aircraft endurance and Civil Aviation Authority (CAA) minimum holding requirements. The limitation on number of sorties flown is accumulated pilot hours which must not exceed 100 for any rolling 30 day period. Main sounding lines were 60 nautical miles long (25 minutes flying time) and were flown in a South East /North West direction, chosen tangential to the coast to reduce the effect of minimum horizontal safety distances. LADS effective sounding swath is 240 metres and lines were spaced 200 metres apart, providing a 40 metre (20 %) overlap. This overlap provided an excellent confidence check on sounding accuracy and object detection. Interlines, fill-ins and reflys were flown only as necessary to ensure full survey area coverage and resolve difficulties with waveform interpretation. Cross-lines were flown at 5,000 metre spacing perpendicular to the main lines of sounding.

One way transit times were 10 minutes from Townsville and 50 minutes from Cairns. Operations from Cairns were also subject to longer taxiing times,

[5] Late afternoon sorties are preferred as they reduce the affects of sun glint on the green laser receiver.

averaging about 20 minutes, as a consequence of being a busy international airport. The flight crews consisted of 2 pilots and an RAN team of 2 LADS operators, in most cases the team that flew the sortie later carried out the validation using the ground processing system. Validation is the most critical phase of survey operations and as such was checked by 3 personnel. Each line was validated by a flight team member, checked by the second member of the team and finally checked and approved by the Charge Surveyor. This process was usually completed within 24 hours of the data gathering sortie. Strict adherence to this procedure meant that few corrections were required when final checking of survey data was carried out prior to rendering to the RAN Hydrographic Office.

Weather Conditions and Effects

Strong south-easterly winds prevailed throughout March and April tending to abate in May. Generally lighter winds prevailed during June - August which was relatively unseasonable. On occasions south- easterly winds with strengths in excess of 30 knots caused difficulty in maintaining the required ground speed on downwind legs and the aircraft had to "race-track", collecting data on the up wind legs only. In these strong wind conditions sea states greater than 4 proved less than ideal for LADS operations. The strong winds increased turbidity, particularly in inshore areas and the rougher sea surface increased beam refraction and scattering, degrading the overall quality of bottom returns and adversely affecting sounding accuracy. In addition, large white caps tended to cause Infra-Red (IR) dropouts and false IR triggers which required tedious editing until a software enhancement automated this process. Optimum conditions for LADS are light to moderate winds with sea states between 1 and 3. Glass calm conditions cause loss of surface returns from the extremity laser spots with consequent degradation of the surface model and possible increased depth errors due to undetected platform tilt. Cloud has significant affect on LADS operations. High cloud, particularly stratus can improve performance by reducing ambient light levels and sun glint. Low cloud (base below 1640 feet) prevents data collection, yielding bright reflections and obscuring firstly the infra-red and then the green laser beam. In North Queensland fair weather cumulus usually had a base between 3,000 and 5,000 feet and did not affect operations however, rain-bearing cumulus sometimes descended below LADS operating height, particularly as the air cooled after sunset.

Horizontal Control/Electronic Position Fixing Equipment

Horizontal control was based on the World Geodetic System 84 spheroid using Australian Map Grid co-ordinates, zone 55. LADS used a Rockwell-Collins 3A Encrypted Precise Code GPS receiver with no differential corrections. Cape Bowling Green Lighthouse and Davies Reef Tower were used as Navigation Check (navcal) points. Results at Cape Bowling Green Light were consistently good, however comparisons at Davies Reef consistently yielded an Easting error of about 28 metres. Surface re-survey of the position of Davies Reef Tower confirmed that the LADS position was correct. Navcals conducted at Cape Bowling Green Light routinely yielded co-ordinate differences of less than +/- 5 metres in both Easting and Northing as long as the GPS Estimated Horizontal Error (EHE) indicated acceptable data (EHE < 12m). The precision of horizontal position for the survey is quoted as

+/- 15 metres (2 sigma). This precision was maintained by rejecting all data when the position confidence, C3, fell to less than 3. The C3 value is calculated by combining the EHE of the horizontal position of the aircraft with the measured stabilised laser platform pitch and roll errors.

Coverage and Productivity

At the end of HI185 approximately 110 million primary soundings had been processed and the area surveyed totalled 2260 square nautical miles with a systematic 20 % double coverage due to the swath overlap between adjacent lines of soundings. Using a secondary sounding reduction radius of 30 metres, final survey data was produced at a ship equivalent survey scale of 1:6000. Disregarding the overlap, LADS averaged approximately 33 square nautical miles fully sounded per sortie which is an extremely credible 66% of the designed maximum (ie. 50 square nm per sortie). The shortfall was due to:

- the combined effects of inclement weather and system defects reducing on-task time,

- the requirement for numerous reflys either to fill in gaps in data caused by GPS constellation changes or to resolve anomalies, and

- the systematic 20 % overlap between adjacent lines.

Navigable Passages

The LADS sounding operations confirmed that two clear passages exist for deep draught shipping between the inner Great Barrier Reef route and the Coral sea. One route through the original Flinders Passage was proposed and surveyed by the Survey Motor Launches and a second navigable passage, which is generally wider, exists further to the west.

Defects/Reliability

Considering the infant operational stage of LADS, the total system has performed credibly during the survey. The reliability of the airborne system is most critical because any failures directly affect productivity. Of the aircraft components, the autopilot gave problems initially, but once resolved, remained reliable. The inertial navigation system caused some flight limitations during July. The stabilised platform pitch control and laser tuner caused the most interruptions to airborne operations during the year but modifications are now in place that should prevent recurrence. The magnetic tape drive remains a weak point in the aircraft system. A graph of air system operational statistics, including defects, is shown below. Both the hardware performance and software functionality of the ground analysis system were below standard at the beginning of the survey. However, increased hard disk capacity, replacement of the processors and numerous software upgrades resulted in a functional and reliable processing system being in place by the end of the survey.

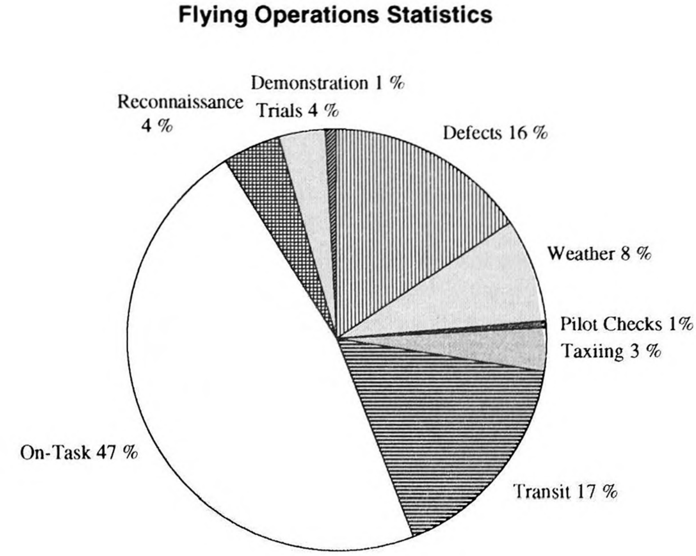

FIG. 4.- Air system operational statistics.

Bathymetry

LADS is essentially a spot sounding system that records depths on an 11 metre grid on each single pass. In practice the laser beam is 2 metres in diameter at the sea surface and diverges as it passes through the water. Examination of overlap areas and comparisons with ship soundings indicate that in average water conditions, full bottom illumination occurs in water depths greater than about 12 metres. Therefore it is not possible for LADS to guarantee finding the least depth of a feature that is less than about 12 metres deep on one pass, though if multiple passes are flown over the feature, the probability of finding the least depth (ie. a direct hit) can be increased. In general water depths less than about 12 metres, isolated features of less than about 8 metres diameter may not be detected by LADS. In general water depths greater than about 12 metres, any feature that is shoaler than the depth at the centre of the laser spot and falls within about 5 metres of the centre would be illuminated by the laser, and in average conditions be indicated on the return waveform. The reflectivity of the feature, its cross-sectional area illuminated by the laser in relation to the illuminated area and the water clarity will all influence the size of the indication and whether the shoal feature is automatically selected as the recorded bottom. When examining significant shoal areas LADS operators examine each waveform and where indication of a significant shoal exists it is carefully investigated, including viewing of the downward looking video records and, if necessary, re-flying the area. Therefore in general water depths greater than about 12 metres it is unlikely that significantly shoaler water than that found by LADS will exist. As water depth increases so does the likelihood of LADS finding the least depth on shoal features. In effect, in general water depths greater than 12 metres, LADS coverage can be considered as similar to side scan sonar operating on the 250m range scale. It is an ideal tool for disproving reported shoals and natural features in clean water, however, man made obstructions, such as masts of a wreck, which have small vertical cross-sectional areas, are unlikely to be detected.

Limitations of LADS Depth Sounding Capability

LADS has the capability of measuring raw water depths from a minimum of about 1.5 metres to a maximum of about 53 metres (the airborne system displays depths to 65 metres), these measurements are then adjusted for "bias" and tide to yield corrected soundings. Within this range the maximum depth performance is actually limited by water turbidity, with LADS able to sound to about twice the Secchi depth. Unfortunately, if no bottom is found the LADS system cannot determine why. The water may be less than 1.5 metres, deeper than 53 metres or simply too dirty to receive laser returns from a seabed depth that actually lies somewhere in between. During validation the operator has to decide where the true seabed lies using his airborne notes, the waveform display, turbidity graph, nearby depths and computed confidence values to assist him in that decision. In the cases where the water is too deep for a seabed return to be received in the prevailing conditions the operator has classified a "No Bottoms At" (NBA) depth at which it can be guaranteed that returns would be received if a bottom did exist.

Comparisons with Ship Soundings

A number of 1:10,000 shoal investigation plots were provided by the Survey Motor Launches and comparisons with LADS normal sounding data yielded encouraging results. In most cases soundings showed good agreement with depth differences usually within +/- 0.3 metres . However, in one shallow water case (shoal of approximately 6 metres) the ship's least depth was 1.5 metres shoaler than LADS, confirming the assessment (above) that LADS cannot guarantee to find the least depth in water depths less than about 12 metres. Comparison of LADS and ship's 1:50,000 sheets show a number of differences within the 30 metre contour near reefs. In all cases LADS had detected additional shoal features not found by the ships. This is not surprising considering the broken nature of the seabed and the 250 metre line spacing of a conventional 1:50,000 survey.

Sounding Accuracy

The accuracy of LADS soundings is dependent on the accuracy of LADS depth measurement and the accuracy of tidal corrections applied. The accuracy of LADS depth measurement is related to the determination of the mean sea surface and the validity of the "bias" correction. A number of factors influence bias in particular the depth, scan angle (which is measured for each sounding) and the scattering of the laser beam (influenced mainly by sea surface roughness and turbidity). The WRELADS, 2 parameter bias model was used for correction of all soundings for HI185. This model corrects for the depth and scan angle factors using an empirically derived mean correction for scattering. Throughout the survey, depth comparisons were routinely conducted between LADS and ground truth "benchmarks" previously surveyed by surface vessels. All benchmark comparison data was passed to DSTO for further analysis and improvement of the 2 parameter bias model. As a result of DSTO analysis of benchmarks comparisons for mission one (7 March to 14 May) a distortion in the WRELADS model was recognised and the "B2" bias model was released in mid November. In-field analysis of all benchmark comparisons has resulted in a correction to soundings greater than 35.0 metres being applied. This correction is in general agreement with the B2 model.

Assessment of LADS sounding accuracy was based solely on comparisons with benchmark areas. As these benchmarks themselves contain errors and the Bowling Green, in particular, was situated in a region more subject to changes of water quality than the survey area, this assessment is considered to be "worst case". It is also worthy of note that due to the strong winds and rough sea conditions during much of the survey the Survey Motor Launches were also unable to achieve IHO standards for depth accuracy.

Overall sounding accuracy, including tidal components was assessed as:

Depth Range	Sounding Accuracy (2 sigma)
< 0.0m	Soundings unreliable due to system limits, should only be used to indicate the presence of drying rocks/reefs.
0.0 - 31.0m	+/- 0.9 metres
> 31.0m	+/- 0.9 metres + 0.01 x (Depth -31.0)

LADS soundings show excellent repeatability when the same area is flown multiple times on the same sortie. However significant differences have been noted when an area is reflown on different days, particularly when sea surface roughness, turbidity and the state of the tide have markedly changed. Undoubtedly inaccuracies in the tidal model contribute to these differences but so do changes in turbidity and more importantly sea surface roughness. LADS could achieve significantly better sounding accuracy by limiting operations to sea states between 1 and 3. In achieving the aim of HI 185, to prove a deep water passage, sounding accuracy was not considered as important as area coverage and detection of shoals, therefore marginal data was accepted and the sounding accuracy assessment consequently suffered.

BUNKER REEF TO FAIRWAY CHANNAL

General

In November LADS commenced operations in its second survey area between Bunker Reef and Fairway channel with the aim of finding a new route that would be more direct and provide deeper water than the existing "two way route". Fifteen sorties were flown in the area during November and December though the survey was not completed by the end of the year. Nevertheless, the significance of weather effects on LADS sounding accuracy is well demonstrated by a looking at the results achieved in this area.

Accuracy of Soundings

The Bunker Reef to Fairway Passage area is more homogeneous in water quality than Flinders Passage and winds remained light throughout, with accompanying low sea states. Sounding accuracy (using the same calculation method as above) was assessed as:

Depth Range	Sounding Accuracy (2 sigma)
0 -31 metres	+/- 0.39 metres - within IHO specifications.

FUTURE ACCURACY IMPROVEMENTS

Improvement to the bias correction is expected when a further refined model is released by DSTO. In addition, work is currently underway to improve the surface interaction algorithm in an effort to reduce the sensitivity of LADS sounding accuracy to changes in sea state.

Conclusion

The first year of operation of the RAN Laser Airborne Depth Sounder has been a remarkable success, both in productivity and in the quality of the output. As with any new system, LADS not been without its teething troubles, however, these were identified and resolved during the course of the year. Additionally, significant software and hardware improvements have been put in place to improve the functionality and reliability of the system as well as reduce the operator workload in the validation phase.

LADS will never replace ships but it has already demonstrated its capability to survey large areas quickly, at a high sounding density producing comparable results to conventional methods in water depths less than 53 metres and superior results in and around dangerous reef areas. The system has proved its ability to achieve IHO specifications for depth accuracy in favourable sea states and developments currently underway are expected to increase the acceptable sea state limits. After one year of operational use LADS has established its position as a key asset of the RAN Hydrographic Service.