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# OFFSHORE TECHNOLOGY REPORT - OTO 97 808

# Measurement of Lung Function Offshore
# Final Report

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# The Measurement of Lung Function Offshore
# Final Report - Feasibility Study

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## Objective

The objective of this study was to assess the feasibility of undertaking lung function measurements, including indices of both gas exchange and ventilatory capacity, on a diving support vessel while at sea.

## Background

Several studies have now demonstrated acute changes in lung function as a consequence of a deep dive. These changes are apparently transient, the decrement in function diminishing with time post-dive. The time taken to return to pre-dive values appears to depend upon the relevant index (Aurora'93). Although the effect of subsequent dives is essentially unknown, a relationship between loss of lung function and diving exposure has been demonstrated. As one of the most pressing problems facing the diving community at the moment is the question of the optimum safe surface interval between deep/saturation dives, the time course of any changes in lung function, and any effect of a subsequent dive, would seem to be an appropriate and important characteristic to investigate. Because of the perceived difficulties in persuading the divers to travel to a suitable testing centre, it has been suggested that they should be examined at their place of work, i.e onboard a diving support vessel (DSV). This approach has the advantage of having the men available both before and immediately after a dive; the men operating from the DSV are in effect a captive group. Such monitoring would faithfully follow standard diving practices and therefore be entirely relevant.

The immediate problems of such an approach are those associated with the practical difficulty of taking measurements onboard a vessel at sea *viz* the potential for equipment malfunction as a result of movement and vibration and the question of accommodation and working practices. Standard laboratory equipment is unsuitable for such use as it is typically both heavy and bulky, the analysers are sensitive to vibration, and the volume transducer is susceptible to movement.

A feasibility study was therefore undertaken to assess the practicality of offshore measurements. This included an initial period of appraisal of new equipment, together with training in the use of said equipment (Stage 1), and a second test period spent at sea assessing the stability of the equipment and the practicalities of measurement (Stage 2).

The following summarises the findings of this feasibility study and contains some material already reported upon (Transflow report, October 1993)

## Stage 1

The equipment, built by PK Morgan plc and to be called 'Transflow', consists of a pneumotachograph for measurement of flow, and solid state analysers for analysis of carbon monoxide (CO), helium (He) and oxygen (O2). The various elements have been incorporated into a package roughly 15 ins wide by 12 ins high by 24 ins deep, which is materially smaller than the standard laboratory unit. Attached to one side is a retractable arm which holds a valvebox which houses the pneumotachograph and mouthpiece. In its original form, inspiration of the test gas was directly from a pressurised cylinder via a demand valve. This gas cylinder is also the source of the gases used for calibration. It is necessary to make adjustments to the valvebox between measurements of transfer factor and ventilatory capacity: these are not trivial, involving removal of an attachment at the distal end of the valvebox assembly and the disconnection of several airlines, but with practice proved to be little problem.

The flow transducer is a standard Fleisch pneumotachograph, calibration being by validation of a pre-set look-up table with facility for periodic check. The test protocols for the flow - volume curve and the breath-hold transfer test are the accepted breathing manœuvres (Lung Function 5th ed: Blackwell 1994) but the measurement protocol for TLCO was subject to a minor modification. Standard techniques call for the collection of a specified *volume* of expirate after the exhalation of a known volume of gas - this is not possible using the Transflow so the exhaled air is sampled for a specified *time* at the correct point. However, the collection time can be adjusted to give an appropriate volume.

In operation the gas analysers were accurate and, under these laboratory conditions, very stable. The procedures are almost fully automated with clear onscreen instructions for the operator. Realtime displays of the data being collected allow monitoring and selection. Calibration is straightforward and rapid enough to allow frequent checks to be made. Repeat testing over two days gave acceptable data for flow-volume indices. However, calculated values for alveolar volume and TLco were significantly more variable than our laboratory would normally find acceptable (coefficient of variation >10%). On subsequent visits to the premises of PK Morgan the variability was eventually found to be due to small changes in the background pressure inside the breathing valve as a direct result of the action of the demand valve. The apparatus supplied for the main study (Stage 2) was therefore modified, the gas mixture being inhaled from a small, non-pressurised inspirate bag. This arrangement gave satisfactory results (see below).

### Stage 2

The Transflow was used to assess lung function on three occasions, i) at Newcastle prior to going offshore, ii) onboard a vessel in the North Sea (Semi-submersible I Rockwater), iii) at Newcastle within two weeks of the offshore measurements. Three subjects were seen each time; additional data was obtained offshore only from a further three subjects drawn from the crew of the vessel.
Indices of gas transfer (Tlco, Kco) and ventilatory capacity (FEV, FVC, flow/volume indices) were calculated and compared to those obtained from standard laboratory equipment (Transfertest model C, McDermott dry spirometer - at Newcastle only). Additional information on reproducibility and ease of measurement on naive subjects was gained from the offshore measurements.

## RESULTS

### The Equipment

The equipment was sent by courier from Newcastle to Aberdeen where it was understood that it would be taken by helicopter from a holding site to the semi-submersible. It was therefore packaged in cardboard boxes with polystyrene supports. In the event it was transported in a container onboard a supply vessel - the return journey was similar. On both trips the boxes were obviously subject to some mishandling and suffered significant damage. Even so, none of the components were damaged and all worked perfectly on setup. The casing for the analysers and controller is metal and very robust and could probably stand up to several trips. The computer is a standard laboratory machine with a CRT display; it is heavy, bulky and relatively fragile and as such gives cause for some concern.

The Transflow was very simple to operate in the field. In fact, no alterations to the initial factory settings for calibration were necessary at any stage, either to the gas analysers or the flow transducer. The only problems encountered were in the laboratory in Newcastle when it was discovered that it is impossible to retrieve data collected if the attached printer is not switched on and functioning correctly.

### Practicalities of measurement

The equipment was set up in the sick bay/hospital - this proved to be an excellent location and was acceptable to the Medical staff. The study was carried out during a period of particularly bad weather (Force 8 winds daily and up to 20 m waves). This meant that no operational diving was carried out over the test period but assurances were given by the senior diving personnel that the test procedures would be easily accomodated. The retractable arm proved to be a potential hazard as it tended to swing quite violently as the vessel pitched. However, such was the stability of the vessel, at no time were measurements unable to be made.

### Gas Exchange

The data collected in Newcastle are given in Table 1. For all three subjects the reproducibility of repeat measurements both within and between test days was acceptable. There was no significant difference between the Transflow estimates of Tlco and Kco and those obtained from the standard laboratory equipment, but there was an apparent tendency for the Translow to over-estimate alveolar volume (VA). With such low numbers the significance of this is uncertain but in any case is immaterial. Such an error due to a calibration problem would be constant and of no consequence to any projected longitudinal study. For each subject both Tlco and Kco measurements made offshore were slightly but not significantly higher than those made at Newcastle (Table 1, a - c).

The offshore data for all six subjects is given in Table 2. Reproducibility is comparable to that expected from standard laboratory-based procedures.

### Ventilatory Capacity

The data for ventilatory capacity and indices derived from the flow-volume curve were reproducible (relevant coefficients of variation within acceptable limits) but the absolute values were low and significantly less than estimated from the standard laboratory equipment. It was subsequently discovered that the Translow had been shipped with a Fleisch pneumotachograph No.2, which, whilst being satisfactory for the transfer factor breathing manœuvre, is inadequate for accurate estimation of the high flows generated during forced exhalation. As a result, the collected data are essentially meaningless and have therefore been ignored.

## COMMENTS

Transportation is hazardous. It will not be possible to convey the Transflow by helicopter, partly because of its bulk but mainly because of the gas cylinder. It will be necessary to leave all the equipment on site for the duration of any study, and if two testing sites are to be used (see below) then two complete sets will be required.

The Transflow performed well under adverse conditions. The choice of the flow transducer was unfortunate but replacement with a Fleisch No.3 will fulfil the necessary requirements. The technology and procedures for measuring flow - volume curves are well proven, it will not be necessary to carry out further testing other than to verify the calibrations. It may well be advantageous to have a separate flow transducer for the ventilatory capacity measurements as this will remove the need to adjust the valvebox between measurements. This should be discussed with PK Morgan.

Other modifications could include an additional fixing for the retractable arm to allow it to be anchored safely, use of a portable computer, and alteration in the programme to eliminate the need to include a printer. The robust metal casing of the main unit should be specified for any future purchase.

Although the weather conditions were bad, the type and size of the vessel attenuated the worst of the effects. Even so, measurements were made when the semisubmersible was rolling enough to throw a standing person off balance. There was no significant vibration apart from some occasional juddering which did not appear to affect the analysers. In any case, vibration testing at the factory had been satisfactory. It is unlikely that the equipment would fail even on a smaller DSV. It is probable that a smaller vessel, particularly a monohull, would be more susceptible to adverse weather conditions. In such circumstances i.e. excessive pitch and roll, it might be impractical or unsafe for personnel to attempt measurement. The possibility of accommodation problems on a smaller vessel, both for the technical personnel and for siting the equipment, should be taken into account.

It is apparent from comments made by the diving supervisory personnel and by representatives of Rockwater that any offshore study will need careful planning and flexibility. The divers change working shifts frequently and somewhat unpredictably and may be required to move to another site at short notice. Two testing stations would increase the numbers of divers studied in any one diving 'season' and reduce the risk of losing subjects. It may also be necessary to plan for permanent manning rather than to attempt to repeatedly move technical personnel. One solution might be to train one or two Life Support Technicians to act as back-up for the lung function technician. This would minimise loss of data if the technician was unable to get to the testing site because of, for instance, transport difficulties.

## CONCLUSIONS

i) The equipment as tested, with minor modifications, is adequate to allow measurement of lung function offshore.

ii) The integration of the necessary procedures with normal diving practices should not be problematical.

iii) The vessel chosen as a testing station should be as stable as possible to minimise the effects of adverse weather conditions.

iv) It would be of great advantage to identify a relatively secure site i.e. where it is known that the work will continue for some months and where the workforce is established.

v) The equipment should be kept on board the vessel for the duration of the study.

vi) Two testing stations would increase subject throughput and reduce data loss.

# TABLE 1 (a)

## Subject 1

| | | Transflow | | | Standard | | |
|---|---|---|---|---|---|---|---|
| Newcastle Pre | | VA* | Tlco† | Kco# | VA* | Tlco† | Kco# |
| | | 5.44 | 7.69 | 1.42 | 5.29 | 8.25 | 1.56 |
| | | 5.53 | 8.02 | 1.45 | 5.39 | 8.19 | 1.52 |
| | | 5.62 | 7.73 | 1.38 | 5.19 | 7.88 | 1.52 |
| | | 5.28 | 7.88 | 1.49 | 5.16 | 7.54 | 1.46 |
| | mean | 5.47 | 7.83 | 1.44 | 5.26 | 7.97 | 1.52 |
| | SD | 0.26 | 0.15 | 0.02 | 0.10 | 0.33 | 0.04 |
| Offshore | | 5.48 | 8.34 | 1.52 | | | |
| | | 5.56 | 8.16 | 1.47 | | | |
| | | 5.62 | 8.28 | 1.47 | | | |
| | mean | 5.55 | 8.26 | 1.49 | | | |
| | SD | 0.07 | 0.09 | 0.03 | | | |
| Newcastle post | | 5.57 | 7.99 | 1.43 | 5.25 | 8.14 | 1.55 |
| | | 5.79 | 8.07 | 1.39 | 5.25 | 7.67 | 1.46 |
| | | 5.90 | 7.78 | 1.32 | 5.22 | 8.19 | 1.57 |
| | mean | 5.75 | 7.95 | 1.38 | 5.24 | 8.00 | 1.53 |
| | SD | 0.10 | 0.15 | 0.06 | 0.02 | 0.29 | 0.06 |

* = Litres

† = mmol. min$^{-1}$Kpa

# = Tlco/VA

# TABLE 1 (b)

## Subject 2

| | | Transflow | | | Standard | | |
|---|---|---|---|---|---|---|---|
| Newcastle Pre | | VA* | Tlco† | Kco# | VA* | Tlco† | Kco# |
| | | 8.82 | 11.53 | 1.31 | 8.66 | 11.52 | 1.33 |
| | | 8.98 | 11.84 | 1.32 | 8.65 | 11.67 | 1.35 |
| | mean | 8.90 | 11.69 | 1.32 | 8.66 | 11.60 | 1.34 |
| | SD | 0.11 | 0.22 | 0.01 | 0.01 | 0.11 | 0.01 |
| Offshore | | 8.70 | 11.90 | 1.37 | | | |
| | | 8.85 | 12.35 | 1.39 | | | |
| | mean | 8.78 | 12.13 | 1.38 | | | |
| | SD | 0.11 | 0.32 | 0.01 | | | |
| Newcastle post | | 8.68 | 11.96 | 1.38 | 8.37 | 10.79 | 1.29 |
| | | 8.83 | 11.29 | 1.28 | 8.30 | 11.04 | 1.33 |
| | | 9.04 | 12.01 | 1.33 | | | |
| | mean | 8.85 | 11.75 | 1.33 | 8.34 | 10.92 | 1.31 |
| | SD | 0.18 | 0.40 | 0.05 | 0.05 | 0.18 | 0.03 |

* = Litres

† = mmol. min$^{-1}$Kpa

# = Tlco/VA

# TABLE 1 (c)

## Subject 3

| | | Transflow | | | Standard | | |
|---|---|---|---|---|---|---|---|
| | | VA* | Tlco† | Kco# | VA* | Tlco† | Kco# |
| Newcastle Pre | | 5.70 | 10.43 | 1.83 | 5.07 | 10.65 | 2.10 |
| | | 5.66 | 10.76 | 1.90 | 5.32 | 11.07 | 2.08 |
| | | 5.62 | 10.67 | 1.90 | | | |
| | | 5.91 | 10.76 | 1.82 | | | |
| | mean | 5.72 | 10.66 | 1.86 | 5.20 | 10.86 | 2.09 |
| | SD | 0.13 | 0.16 | 0.04 | 0.18 | 0.30 | 0.01 |
| Offshore | | 5.46 | 11.15 | 2.04 | | | |
| | | 5.42 | 11.10 | 2.05 | | | |
| | | 5.35 | 11.06 | 2.07 | | | |
| | mean | 5.41 | 11.10 | 2.05 | | | |
| | SD | 0.06 | 0.05 | 0.02 | | | |
| Newcastle post | | 5.38 | 10.82 | 2.01 | 5.14 | 10.89 | 2.12 |
| | | 5.38 | 10.91 | 2.03 | 5.24 | 11.47 | 2.19 |
| | mean | 5.38 | 10.87 | 2.02 | 5.19 | 11.18 | 2.16 |
| | SD | 0.00 | 0.06 | 0.01 | 0.07 | 0.41 | 0.05 |

* = Litres

† = mmol. min$^{-1}$Kpa

# = Tlco/VA

## TABLE 2

### Transflow

| | | VA* | Tlco† | Kco# |
|---|---|---|---|---|
| Subject 1 | | 5.48 | 8.34 | 1.52 |
| | | 5.56 | 8.16 | 1.47 |
| | | 5.62 | 8.28 | 1.47 |
| | mean | 5.55 | 8.26 | 1.49 |
| Subject 2 | | 8.70 | 11.90 | 1.37 |
| | | 8.85 | 12.35 | 1.39 |
| | mean | 8.78 | 12.13 | 1.38 |
| Subject 3 | | 5.46 | 11.15 | 2.04 |
| | | 5.42 | 11.10 | 2.05 |
| | | 5.35 | 11.06 | 2.07 |
| | mean | 5.41 | 11.10 | 2.05 |
| Subject 4 | | 9.98 | 15.71 | 1.57 |
| | | 9.74 | 15.35 | 1.58 |
| | mean | 9.86 | 15.53 | 1.58 |
| Subject 5 | | 8.43 | 13.01 | 1.54 |
| | | 8.24 | 13.50 | 1.64 |
| | mean | 8.34 | 13.26 | 1.59 |
| Subject 6 | | 8.31 | 12.78 | 1.54 |
| | | 8.25 | 12.72 | 1.54 |
| | mean | 8.28 | 12.75 | 1.54 |

* = Litres † = mmol. min$^{-1}$Kpa # = Tlco/VA