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AEROSPACE RECOMMENDED PRACTICE

ARP 1109 A

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ENTIRE PRACTICE REVISED

DYNAMIC TESTING SYSTEMS FOR OXYGEN BREATHING EQUIPMENT

1. PURPOSE: This document recommends performance requirements for test equipment used in dynamic testing of aviation oxygen breathing equipment.

2. SCOPE: This ARP describes test equipment and methods used for testing continuous flow, demand and pressure demand regulators and their associated masks as well as filtered protective breathing devices; such articles of oxygen breathing or protective breathing equipment may be tested as individual components or as a complete system.

2.1 Classification: This recommended practice covers but is not limited to the following types and classes of systems:

2.1.1 Types:

Type I Mechanical breathing simulator (either bellows or piston type) only generating sinusoidal patterns

Type II Mechanical breathing simulator (generally cam-actuated, bellows or piston type or pre-programmed, servocontrolled) generating any shape of breathing pattern

Type III Pneumatic breathing simulator pre-programmed, servocontrolled generating any shape of breathing pattern

2.1.2 Classes:

Class A Military aircraft oxygen systems
Class B Transport category and General Aviation oxygen systems

2.1.3 Altitude Range:

Altitude range	Usual range of breathing pressures at maximum altitude		
	in. water	mbar	kPa
40,000 ft	5.0	12.5	1.25
50,000 ft	30.0	74.7	7.47
above 50,000 ft	43.5	108.4	10.84

NOTE: This classification applies whether the breathing simulator is an individual system or if it is permanently incorporated into a complete test set-up.

2.2 Reference Documents:

2.2.1 SAE:

AIR 1176 Oxygen System and Component Cleaning and Packaging
ARP 1398 Testing of Oxygen Equipment
AS 8010 Aviators Breathing Oxygen Purity Standard
AS 8025 Passenger Oxygen Mask
AS 8026 Crew Member Demand Oxygen Masks
AS 8027 Crew Member Oxygen Regulators, Demand
AS 8031 Minimum Performance Standard for Personal Protective Devices for Toxic and Irritating Atmospheres, Air Transport Crew Members

2.2.2 Others:

MIL-O-27210 Oxygen Aviator's Breathing (ABO)
MIL-G-27617 Oxygen Lubricants
MIL-P-27401 Nitrogen, type I
ASCC Air Standards 61/10B and 61/22, 18 Aug 82
NATO STANAG 3865, 19 June 84

3. REQUIREMENTS:

3.1 Breathing Simulator: The breathing simulator shall simulate human respiratory flows. In order to permit ventilation extremes to be attained, it is desirable that the following parameters be adjustable over a wide range:

- Ventilation (liter/min), or Minute Volume (MV),
- Peak flow, inspiratory and expiratory (liter/min) (PF),
- Rate of flow change, inspiratory and expiratory (liter/sec^2) (RFC),
- Frequency or breaths per minute (B.P.M.)
- Tidal volume (liter), (TV),
- Ratio of Inspiratory time to Total Cycle time. For simplification, a constant ratio of 0.5 shall be acceptable.

3.1.1 Breathing Simulator, Class A (Military Aircraft): Such a simulator shall be capable of performing according to the range of settings as defined in Table I.

TABLE I

RANGE OF SETTINGS		Min.	Max.
VENTILATION (l/min)	MV	5	65
PEAK FLOW (l/min) Insp & Exp	PF	12	210
RATE OF FLOW CHANGE INSP. AND EXP. (l/sec^2)	RFC	± 3	± 20
FREQUENCY	BPM	7	60
TIDAL VOLUME (l)	TV	0.5	2.5

3.1.2 Breathing Simulator, Class B (Transport Category Aircraft): Such a simulator shall be capable of performing according to the range of settings as defined in Table II.

TABLE II

RANGE OF SETTINGS		Min.	Max.
VENTILATION (l/min)	MV	8	30
PEAK FLOW (l/min)	PF	12	110
RATE OF FLOW CHANGE (l/sec^2)	RFC	± 3	± 11
FREQUENCY	BPM	7	35
TIDAL VOLUME (l)	TV	0.5	1.1

3.1.3 Workloads (See Ref. 2, Page 13): It is desirable to combine the various settings as defined in Table I and Table II above, so as to simulate realistic breathing conditions correlated in the different ranges outlined in Table III and corresponding to defined WORKLOAD CONDITIONS.

Also see Bibliography, Reference 2, Table 2.2.

TABLE III

WORKLOAD CONDITIONS										
CONDITION	WORK RATE W (watt or joule/s)		MV 1/min		PF RANGE 1/min		BPM	
REST	min 0	max 0	min 7	max 14	min 25	max 50	min 6	max 18
LIGHT	8	50	15	25	45	70	12	22
MODERATE	50	80	25	35	70	100	20	30
MEDIUM	80	160	30	50	100	170	22	35
HEAVY	> 160		40	65	170	210	25	50*

*hyperventilation condition, for short duration only.

4. CYCLIC FLOW TEST PROCEDURES:

4.1 Simulation of a Given Ventilation (MV) 1/min ATPD with a Sinusoidal or Near Sinusoidal Flow Profile:

Two parameters will be set:

- Frequency (BPM)
- Tidal Volume (TV) or Minute Volume (MV)

4.1.1 BPM Calibration: BPM can be set and verified by means of a stop-watch on a reasonable time basis (1 to 3 minutes). It is preferable to start with BPM adjustment due to precision of time measurement. A precision of 0.01 (one percent) can easily be achieved. Some simulators may have a BPM adjustment dial accurate enough for the purpose.

Computer controlled simulators do not need BPM adjustment.

4.1.2 TV or MV Calibration: TV or MV calibration may be carried out "ON LOAD" or "OFF LOAD". It is general practice to calibrate simulators "OFF LOAD" i.e., with the lowest resistance to simulator flow (with the inspiratory and expiratory mask valves or equivalent). All pipe lengths must be kept to a minimum. The correct TV or MV can be calibrated by adjusting the stroke of type I and type II simulators or the equivalent feature of type III, the correct MV being measured on an appropriate gas meter or spirometer. Precision on MV and TV depends on the duration of the calibration test (at least 3 to 5 min). A 0.01 (one percent) precision can be achieved provided adequate corrections on pressure, temperature and humidity are applied to the test results.

4.1.3 Simulation of a Given Ventilation (MV) 1/min BTPS in Same Conditions as for 4.1: Unless if the simulator can be remotely adjusted at altitude with sufficient accuracy (type I and II) or pre-programmed (type II and III), the simulator shall be calibrated at ground level for the ATPD MV equivalent to the BTPS MV at the required altitude prior to testing at this altitude.

4.2 Simulation of a Given PEAK FLOW (PF) 1/min ATPD (either inspiratory or expiratory, or both):

4.2.1 Type I Simulator (Sinusoidal): Peak flow can easily be computed as follows:

$$TV = \frac{PF}{\pi \times BPM} \text{ liter}$$

$$PF = \pi \times BPM \times TV$$

$$PF = \pi \times MV \text{ liter/min}$$

But, due to factors such as mechanical imperfections or simulator pneumatic lines impedance, it is preferable to measure PF as in para 4.2.2.

4.2.2 Type II and III Simulators (Figure 1): A pneumatic "FLOWCAN" (or Fleish pneumotachograph of appropriate size and calibration or a flowmeter of equivalent performance) must be connected between the simulator outlet and the mask valves. A differential pressure transducer must be connected to the tappings upstream and downstream of the FLOWCAN. A suitable oscilloscope and/or recorder must be connected to the transducer.

Note: Such flowmeters shall be calibrated in either direction of the breathing flow.

A 0.03 to 0.04 (three to four percent) range of precision can be achieved on PF readings. If flow profile is generated by means of a cam-actuated simulator, the cam profile must be adjusted until the requested PF is generated.

Servo-controlled simulators allow for continuous and accurate adjustment of TV and BPM and can create a wide variety of flow profiles including square wave generation, human breathing reproduction, etc.

4.3 Rate of Fow Change (RFC):

4.3.1 Type I Simulator (Sinusoidal): RFC can easily be computed as follows:

$$RFC = 2\pi \times BPM \times PF \quad 1/min/min \text{ or } 1.min^{-2}$$

$$RFC = \frac{2\pi \times BPM \times PF}{60} \quad 1/min/s \text{ or } 1.min^{-1}.s^{-1}$$

$$RFC = \frac{2\pi \times BPM \times PF}{3600} \quad 1/s/s \text{ or } 1.s^{-2}$$

or

$$RFC = 2\pi^2 \times TV \times BPM^2$$

$$= 2\pi^2 \times BPM \times MV \quad 1/min/min \text{ or } 1.min^{-2} \text{ etc.}$$

For the same reasons as in para 4.2.1, it is preferable to measure RFC as in the following paragraph:

4.3.2 Type II and III Simulators (Figure 2): In stabilized conditions, record PF versus time as indicated in para 3.2.3.2 on a large scale XY recorder. Draw a tangent line from the origin of the breathing cycle.

$$RFC = \text{Flow rate/time or } \tan \alpha$$

Alternatively, RFC may be determined by electronically differentiating the breathing flow signal.

Note: Due to performance limitations of certain mechanical simulators, it is necessary to simulate high values of PF and RFC with higher BPM than human breathing in same conditions. This method should be restricted to stability and resistance to flow testing.

4.4 Simulation of Human Breathing System Impedance: The most sophisticated breathing simulator is unable to exactly reproduce the elements of the human breathing system impedance; for example, the dead volumes, the elasticity, the local and variable resistance to flow of the lungs, mouth, nose and air ways.

This should be kept in mind when connecting the equipment to be tested to a given simulator.

This is particularly important when testing miniature servocontrolled oxygen regulators whose performance is to be evaluated and verified as a closed loop system interfacing with users and their personal equipment.

For instance, piston-type simulators may develop higher PF and RFC than calculated due to transmission imperfections. Simulators using flexible bellows may induce regulator outlet pressure instability due to their own natural frequency.

Studies carried on by RAE Farnborough (UK) (Bibliography, References 3, 4 and 5) give useful directions for simulating the human breathing system impedance when using breathing simulators.

4.4 (Continued):

Another example of such a simulation is given in Fig. 6, representing the breathing simulator specified for testing continuous flow masks.

4.5 Dilution Testing: The intent of dilution testing in dynamic conditions is to measure the mean oxygen percent or the mean partial pressure of oxygen in the inhalation portion of the breathing cycle.

As breathing simulators can only approximately reproduce human breathing in its variety and complexity, great care should be taken in the definition of dilution testing criteria on a given simulator as well as in the interpretation of the test results.

For a given test, three parameters will be clearly defined:

- Minute volume (MV),
- Breaths per minute (BPM),
- Peak flow (PF) or Rate of Flow Change (RFC)

Different procedures may be considered. They will vary according to the size of the altitude chamber to be used.

4.5.1 Dilution Testing in Large Size Altitude Chamber (0.4 to 0.5 cubic meter minimum, see Figs. 3, 4, and 5): A large altitude chamber can accommodate the breathing simulator. It allows for high differential breathing pressure testing when the simulator is not built for sustaining these differential pressures. The exhaled gas can be dumped directly in the chamber if a high "ventilation rate" of the chamber atmosphere is maintained through the air inlet valve provided the chamber vacuum pump can maintain chamber pressure altitude as required. This prevents the oxygen concentration in chamber ambient from exceeding 21%. In addition, the exhaled gas should be dumped as close as possible to the chamber vacuum pump port.

4.5.2 Dilution Testing in Small Size Altitude Chamber (See Fig 4): The breathing simulator must be located outside the chamber and must withstand the necessary differential breathing pressures between ambient pressure and chamber pressure.

The exhaled gas must be collected at the exhalation valve port, and dumped into an outside plenum connected to the vacuum line.

4.5.3 Oxygen Concentration Measurement: Partial pressure (pO_2) analyzers are most commonly used. Several types are available using the following principles:

- polarographic, galvanic, metal oxide,
- paramagnetic, mass spectrometric, etc.

Those analyzers need to be frequently calibrated both at ground level and also at altitude. (Using ambient air and pure oxygen. Pure nitrogen can also be used at ground level.)

4.5.3 (Continued):

Polarographic cells can be directly plugged into the breathing line. These cells need to be replaced from time to time.

Paramagnetic cells call for a small sample of breathing gas to be diverted from the breathing line and directed to the cell.

This sample (approx. 1 liter/minute ATPD) can be dumped into the vacuum line (Fig 3).

In this case, the pO_2 reading must be corrected by the factor $\frac{P1}{P2}$.

When the gas sample is being collected by means of a small diaphragm pump, the gas sample can be either dumped into the chamber (Fig 5) or re-injected in the exhaled flow (Fig. 4). In that case, no pressure correction is needed.

4.5.4 Location of Breathing Gas Sampling at the Regulator Outlet (Fig. 3): Depending on the regulator design, pO_2 measurements may be found difficult due to pressure fluctuations developed by the regulator itself.

Due to subsequent fluctuation of pO_2 within the inhalation cycle, sampling at the regulator outlet may not be the best location.

4.5.5 Sampling on the Exhalation Line (Fig. 5): With this method, the inhaled gas mixture is being homogenized due to the turbulence into the simulator cavity and connecting lines. An additional mixing chamber of appropriate design can also be used between the mask expiratory duct and the sampling point. It is also desirable that some plenum (or significant length of hose or pipe) be provided downstream of the sampling point in order to prevent chamber ambient gas backflow up to the sampling point.

4.5.6 Alternative Methods:

- Using measured minute volume and measured inlet oxygen flow allows calculation of total oxygen concentration

- When testing in small size altitude chamber, one can use measured minute volume and measured inlet air flow to the chamber at stabilized altitude for calculation of total oxygen concentration.

4.6 Cyclic Flow Test Procedure for Continuous Flow Masks (Fig. 6): Fig. 6 is part of AS 8025 (Fig. 8, page 29). This proposed standard describes in paragraph 6.1.7.2 the recommended test procedure for dynamic testing of continuous flow masks. A breathing simulator Type 1 Class B Altitude range 40,000 feet will meet the purpose.

5. GLOSSARY:

FREQUENCY OR BREATHS PER MINUTE (BPM)

Number of breaths per minute by the subject

PEAK FLOW (Inspiratory and expiratory) (PF)

Maximum flow of gas during inspiratory or expiratory phase

RATE OF FLOW CHANGE (RFC)

Time derivative of inspiratory or expiratory flow

TIDAL VOLUME (TV)

Volume of gas inhaled per breath

VENTILATION OR MINUTE VOLUME (MV)

Volume of gas inhaled per minute by the subject

6. BIBLIOGRAPHY:

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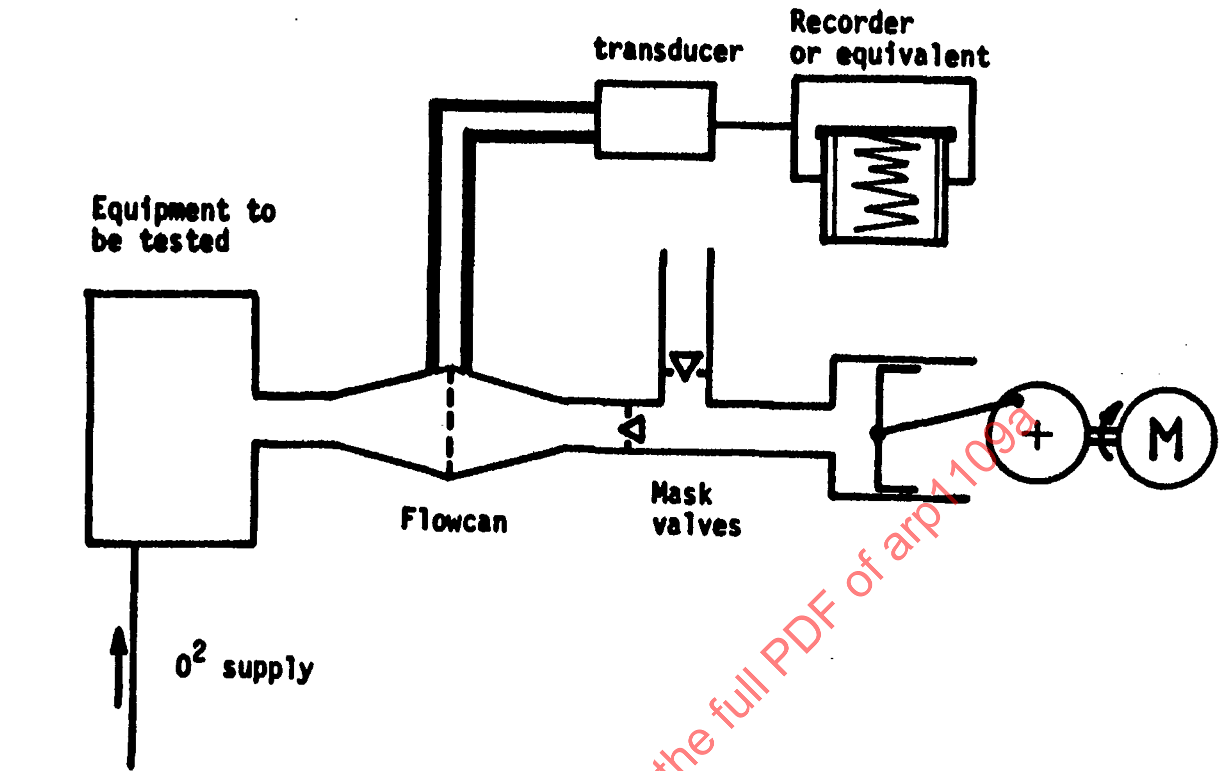

FIGURE 1 - SCHEMATIC PEAK FLOW (PF) CALIBRATION

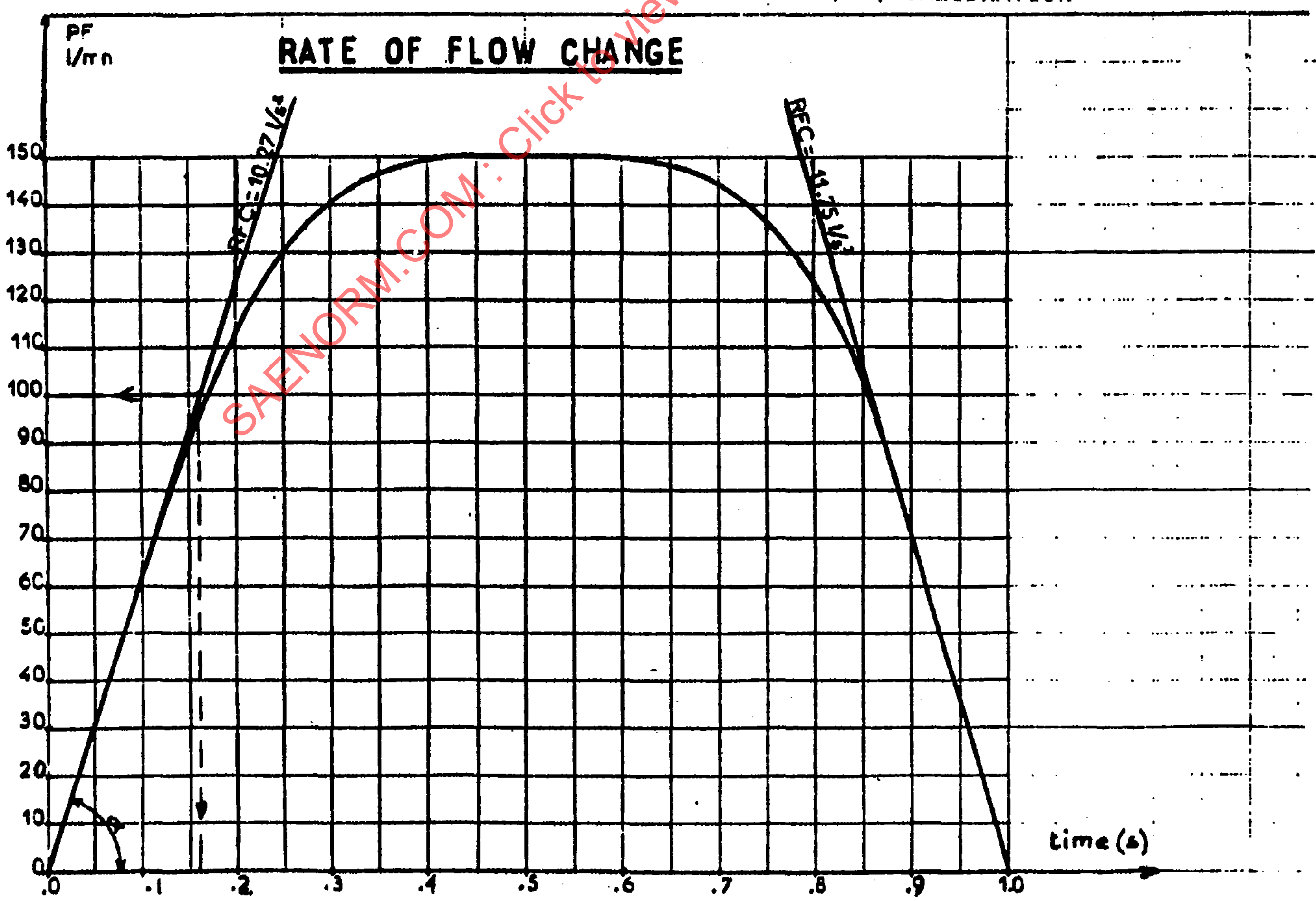

FIGURE 2

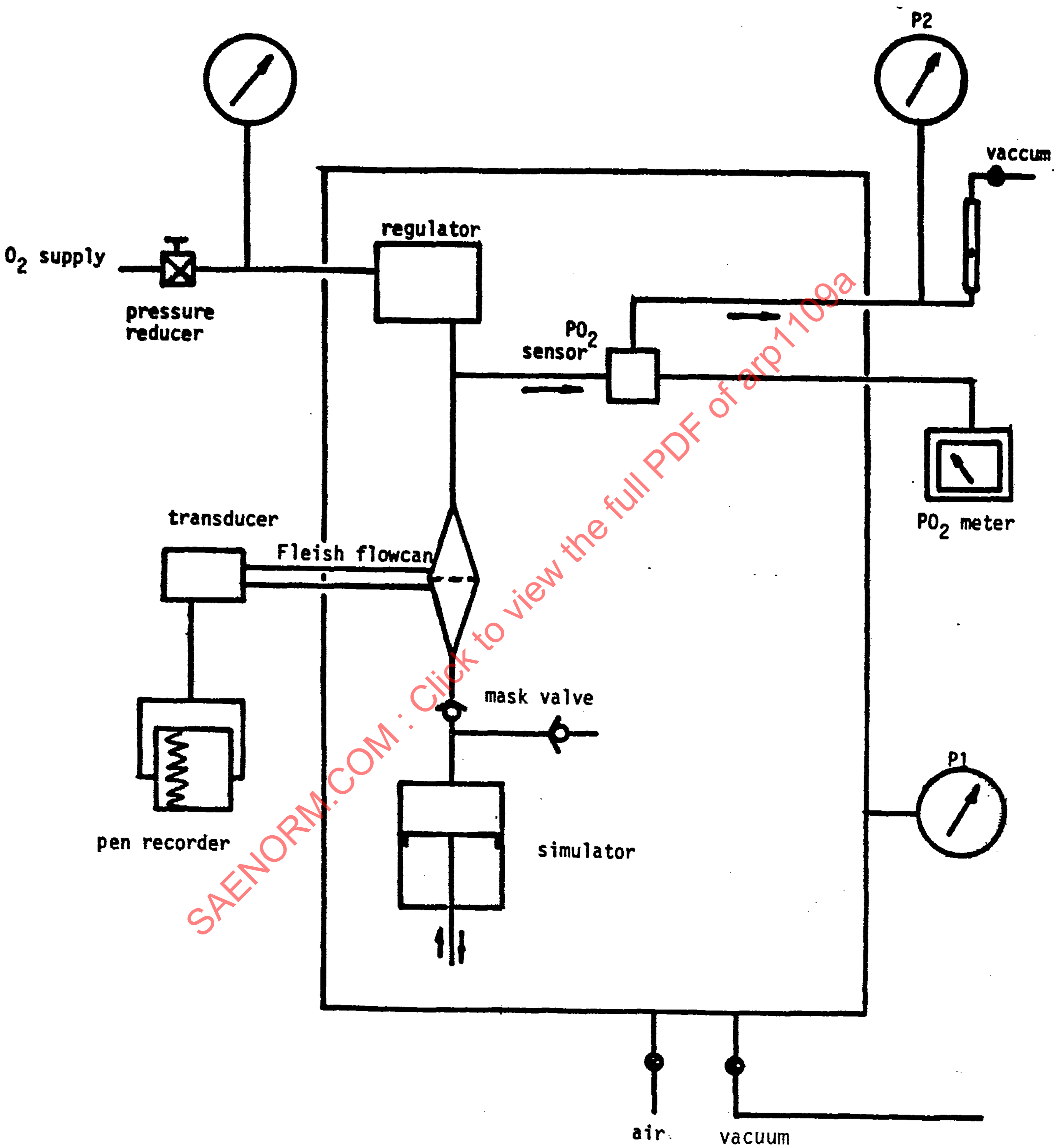

FIGURE 3 - BREATHING GAS SAMPLING AT THE REGULATOR OUTLET

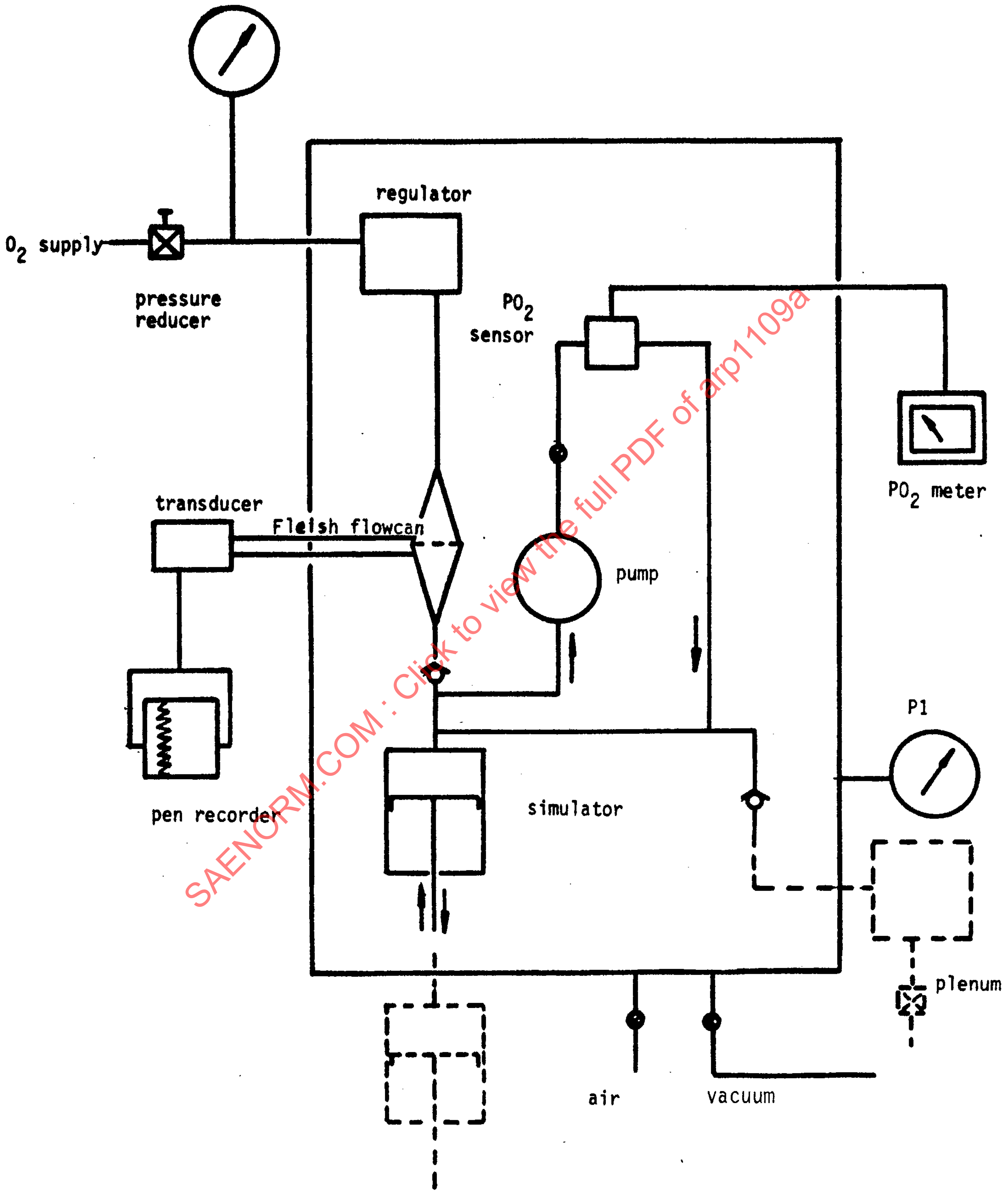

FIGURE 4 - BREATHING GAS SAMPLING AT THE REGULATOR OUTLET THROUGH A PUMP