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DEVELOPMENT OF A LOW RESISTANCE FACEPIECE
FOR COLLECTION OF EXPIRED GASES

Thesis for the Degree of M. S.

MICHIGAN STATE UNIVERSITY

Thomas D. Temple

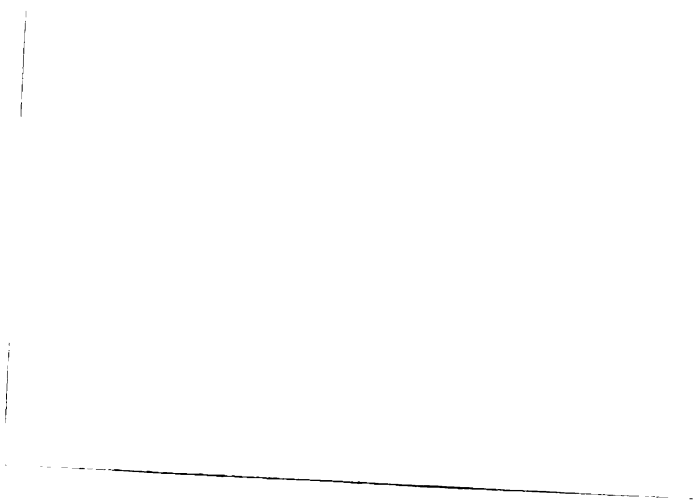
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ABSTRACT

DEVELOPMENT OF A LOW RESISTANCE FACEPIECE FOR COLLECTION OF EXPIRED GASES

by Thomas D. Temple

The objective of the thesis was to develop a low resistance, half mask facepiece for use in open circuit energy metabolism measurement. The need for such a mask in exercise investigation is self-evident. This study begins with the basic design of the mask and valve system and proceeds through construction to the ultimate testing of a prototype mask.

The most important test criterion was the dynamic airflow test in which intramask pressures were recorded. The volume of the respiratory dead space within the mask was also recorded.

The basic mask configuration is triangular; with two valve groupings, three "J" valves per group. Three inhalation valves are on one side and three exhalation valves are on the other. The top valve is approximately opposite the nostril on its side. Reducing cones fitting over the valve groups allow for attachment of hoses.

The mask was designed and molded on a sculptured face. The dimensions of which were taken from available physical anthropometric data.

The construction plan was simple. The first step was to sculpture the average face. Then on this face

the exterior contours of the mask were formed with oil base designers clay. Using Ultra Cal 30 molds were poured of these exterior contours one half at a time. Within the exterior molds the interior contours were sculptured and Ultra Cal molds were cast of the interior, again one half at a time. Then the corresponding interior and exterior molds were placed together and formed two semicavity molds. The final prototype mask was made by pouring Dow Corning RTV 589 Silastic into the molds and then laminating the resulting halves together.

To determine the effectiveness of the facepiece intramask pressures reflecting inhalation and exhalation resistances were measured at varying air flow rates.

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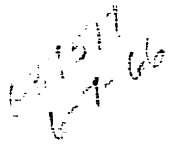
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I wish to thank Dr. Wayne VanHuss for his advice and council. His kind encouragement made the completion of this thesis possible. Also, I must acknowledge the work of Mr. Daniel Sipila. Through his imagination, ingenuity and creativity the technical problems of mask construction were solved. It was his skillful manipulation of the raw materials that forced an idea into a finished product.

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CHAPTER I

INTRODUCTION

Introduction to the Problem

If Physical Education is to grow as a profession its members must be willing to engage in basic research. In research quite often it is necessary to develop equipment for a specific purpose. The current work is concerned with improvement of equipment necessary for the measurement of energy metabolism during high intensity exercise. The purpose of this study was to develop a comfortable, low resistance mask for use in the collection of expired gas.

Research on respiratory protection devices and facepieces has accelerated since World War I with the advent of chemical warfare and high altitude aviation. The armed forces and the Bureau of Mines have promoted extensive research and development in this area. Silverman in particular, and others have investigated the physiological effects of inspiratory and expiratory resistance in masks. Silverman's work has provided guide lines for protective masks used in low intensity exercise. His data, however, were not extended to

high intensity exercise. The Warren Collins Company has developed low resistance respiratory valves and have published their resistance curves.* The Bureau of Mines has recently published data concerning mask fit and average dimensions.

The facepiece whose design and construction will be outlined in this paper was created specifically for use in open circuit expired gas collection equipment. In this procedure a true sample of the subject's expired gases is necessary for accurate computation of oxygen consumption. Too much care cannot be taken to preserve the purity of the sample. This necessitates an air tight system from the subject to the collection bag or gas analyzer. Silverman has shown that excessive resistance in the system results in lowered ventilations, oxygen intake, and greater true oxygen values (2). Since in most studies it is the desire of the researcher to evaluate work expenditure under standard conditions, such discrepancies tend to increase variabilities.

An evaluation of the respiratory resistances of various combinations of masks, valves and hoses used in the Human Energy Research Laboratory at Michigan

*Catalog of Warren E. Collins, Inc., 555 Huntington Avenue, Boston 15, Massachusetts.

State University for gas collection in measuring energy metabolism has been made by VanHuss and associates. It was found that the most functional unit included the Collins Triple J valve, British corrugated tubing, five way Hans Rudolf valve and plastic Douglas Bags (7).

Unfortunately, the use of the Collins Triple J valve necessitates the use of a mouthpiece and nose clamps which are uncomfortable for the subject being tested. A subject can't swallow with the mouthpiece in place nor can dentures be worn while using it. The nose clip often slips thus invalidating the testing. The Collins Triple J Valve, no matter how it is attached, is a cumbersome unit. The subject must be trained to wear it before it can be used for accurate testing.

VanHuss found that by using a full face gas mask produced by the Acme Protection Equipment Company* and fitting it with either the Siebe-Gorman or the plastic Franz-Muller valves they were able to make the subjects comfortable. However, neither valve was satisfactory for high intensity work due to poor resistance characteristics. It was difficult to fit the mask, the mask was subject to fogging; eye glasses could not be worn with the mask and subjects wearing it occasionally complained of claustrophobia.

*Acme Protection Equipment Company, South Haven, Michigan.

It was reasoned that a half mask incorporating a system similar to that used in the Collins Triple J valve should eliminate the problems stated above.

Since no facepiece of this type was available the problem undertaken in this thesis was to design, construct and test such a mask.

Scope of the Study

This project began with the basic design of the mask and proceeded through construction to the ultimate testing of a prototype mask. It was the author's intent to incorporate into the mask the following characteristics:

1. Low resistance to air flow through the valves
2. Minimum dead air space
3. Negative static air leakage; negative dynamic air leakage
4. Minimum valve opening pressure
5. Maximum comfort
6. Airtight fit on the maximum number of subjects
7. Minimum mask weight
8. Maximum ease of cleaning

The most important test criterion was the dynamic air flow test in which intramask pressures were recorded. The volume of the respiratory dead space within the mask was also recorded.

Since this is a prototype mask, no extensive fit nor practical usage tests were planned. The prototype was primarily to test the practicality of a half mask with an integral low resistance valve system.

Comfort and ease of cleaning are subjective characteristics that do not lend themselves to empirical testing. Since this prototype facepiece is not to be fitted on, nor exposed to a large number of subjects the testing of these two items has not been included in this study.

The static and dynamic valve leakage as well as the minimum valve open pressure characteristics will be reflected in the intramask pressure recordings, so individual tests of these measures are unnecessary.

Laboratory conditions limited our selection of mask construction material, consequently the final prototype mask was subjectively rated by the author as exceeding the allowable weight for convenient use.

Definitions

1. Half mask facepiece--Refers to a mask which encloses the wearer's nose, mouth and chin.
2. Integral low resistance valve system--A system of nonfiltering, nonabsorbent inspiration and exhalation valves built into and forming an integral part of the face piece.

3. Energy metabolism measuring equipment--That apparatus used to collect expired gases for analysis and computation of energy expenditure for a given amount of work.
4. Dead air space--That volume of air within the facepiece cavity which may be re-inspired with each subsequent inhalation.
5. Low resistance--Having a resistance to air-flow during inhalation or exhalation of less than 20 mm H₂O.
6. High intensity flow rates--Flow rates in excess of 100 l/m and up to approximately 300 l/m.

CHAPTER II

REVIEW OF THE LITERATURE

The first logical attempt to use physical anthropometric measures as the basis for equipment construction was made by the Aero Medical Laboratory of the Army Air Force in 1942. They collected facial measurements of 1,454 male and female flying personnel. Later they measured an additional 1,500 to check the original findings and on these data based the construction of the oxygen mask for flying personnel (1). This body of data was not available but certain key measurements, face length, nasal bone length, face width and mouth width, were presented in the Respiratory Protective Devices Manual published by the American Industrial Hygiene Association and American Conference of Governmental Industrial Hygienists (4). These figures match very closely the means of identical measurements obtained by Todd and Lindala (6). The Todd and Lindala study covered 268 males and females of both the Negro and Caucasian races. Facial measures extracted from Todd and Lindala supplemented the Air Force data in the Respiratory Manual and were used to complete the

construction of a model of an average face upon which the facepiece in this study was constructed.

The Respiratory Protective Devices Manual provided excellent guide lines for half mask facepiece construction. It states that the single most important measurement in half mask design and fit is the face length, measurement A, Figure 1, (4:20). No matter what the basic shape of the mask the wearer's face length must be within its range to obtain a proper fit. To obtain a proper fit the nose cup of the half mask must seal on the nasal bone, the slightest pressure on the nose below this bone compresses the nares and interferes with inhalation. The allowable half mask length variation cannot exceed 12 mm. This is the average length of the nasal bone according to the Army Air Force measurements.

The mouth width is also an important measurement, for it fixes within certain limits the facepiece width. The facepiece must seal on the boney structure at least 1-inch, (12.5 mm), to the rear of the teeth. A mask sealing on the fleshy tissues over the teeth will cause chafing and result in extreme discomfort. The Respiratory Manual states that it would probably take five mask sizes to insure a proper fit on all persons.

Also important to good fit is the configuration of the mask peripheral sealing surface. The most common type and the type used on the Army M-9 assault mask is

TABLE I
SELECTED SIZES OF TYPE A HALF MASKS (4:21)

Facepiece	Observed Population In Size Range %	Face Length mm.	Length Of Facepiece mm.	Face Width mm.	Width Of Facepiece mm.
1	1	96-108	102	40-50	75
2	21	107-119	113	45-55	80
3	69	118-130	124	50-60	85
4	27	129-141	135	55-65	90
5	1	140-152	146	60-70	95

the flat peripheral surface. This surface provides leak proof seals as shown by Army tests. The facepiece also must be made of a flexible enough material so that it can contact all facial contours.

Very important in facepiece construction considerations are the intramask pressures. These intramask pressures reflect the respiration resistances inherent in the mask. Respiratory resistances have been shown to produce variations from normal respiratory patterns.

VanHuss and Heusner in testing masks of varying resistance found that greater resistance was responsible for significantly impairing respiratory rate and respiratory minute volume. Also that the inspiration time, inspiration time as a per cent of the breathing cycle and the amount of oxygen absorbed per liter of air breathed were all significantly greater (8). In agreement with Silverman's data presented in the Respiratory Protective Devices Manual showed the effects of resistance to be reduced minute volume, reduced inspiratory flow, reduced expiratory flow and reduced respiration rate.

Silverman suggests that to obtain a complete evaluation of a respiratory valve it should be tested for resistances through a complete range of physiologically possible flow rates.

Instantaneous inspiratory air flows under sedentary conditions attain values as high as 40 l/min. depending upon the minute volume and resistance to breathing. At maximum effort, however, peak flows over 300 l/min. have been obtained in individual subjects with a mean value without resistance of 286 l/min. for a group of three subjects (8:12).

Accordingly, for a thorough test a valve should be tested at airflows from approximately 40 l/min. to 300 plus l/min.

Silverman arbitrarily formulated the following table to classify air flow resistances.

TABLE II
ARBITRARY TABULATION FOR RATING RESISTANCE
OF EXHALATION VALVES (8:28)

Air Flow	Air Flow Rate l/Min.	Low	Resistance, mm H ₂ O Medium	High
Low	50	<7	<12	>12
Medium	150	<21	<36	>36
High	250	<35	<60	>60

VanHuss states that according to Matthes* respiratory compensations are necessary to adjust for inhalation or exhalation resistances as low as 20 mm H₂O (7). In the same paper VanHuss and his co-workers tested various

*Matthes, N. V., "Die Bedeutung des Atemwiderstandes für die Messung des Respiratorischen Stoffdwechsel." Arbeitsphysiologie, 11:117-128, 1946.

commercially available two way respiratory valves in circuit with flex hose and Douglas Bag. They found that with the Siebe-Gorman valve intramask pressures exceed 20 mm H₂O at 86.2 l/min. and with the Franz-Muller Valve at 109.9 l/min.

The following data was supplied for Webb and Associates for their evaluation of the Army M-17 Assault Mask by the Mine Safety Appliances Company (9). Number two was classified as a medium resistance mask, number three consists of an M-17 body with zero-resistance filter element blanks installed for the purpose of maintaining the shape of the mask, number four is classified as a low resistance facepiece, the standard is the M-17 mask intact.

TABLE III
FLOW RESISTANCE DATA SUPPLIED BY MSA FOR
EXPERIMENTAL MASKS (9:28)

Designation	@ 85 lpm	Pressure Differential, mm H ₂ O	
		@ 100 lpm	@ 300 lpm
Standard	43	58.5	225
#2	30	42	200
#3	3	5	35
#4	14	35	136

Respirator dead space also of importance in mask construction, is defined as the volume of air included

within the respiratory cavity. This volume becomes contaminated with CO_2 from previous exhalations and is subsequently inspired on each succeeding inhalation. It is considered insignificant if it does not exceed 150-200 ml. (8).

The Respiratory Manual points out that from the standpoint of resistance the best position for the exhalation valve is at a point midway between the nose and the mouth (8).

Tait (5) states that a head harness type of suspension provides improved fit and increased stability for the half mask facepiece. The two strap, four attachment point type suspension approaches most nearly the ideal.

CHAPTER III

METHODOLOGY

A half mask to insure proper fit must seal on the nasal bone and on the boney structures of the lower face. According to data quoted in Chapter Two a half mask having a length of 124 mm. and 85 mm. width should do this for 69 per cent of the adult population. The actual dimensions of the half mask in this study are 130 mm. width. By extending the length 6 mm. the mask should fit a greater percentage of the adult population. The greater length will allow greater width flexibility. Also, since in the Respiratory Manual data there is a 6 mm. overlap in sizes, increasing the mask length will allow this mask to fit not only those persons normally capable of wearing this size, those within one standard deviation above and below the mean, but it will also fit those one and one-half standard deviations above the mean. If this logic holds true, the mask should fit approximately 80 per cent of the adult male and female population. Other dimensions and interior contours were approximated on the average constructed according to measurements in Table I.

The basic mask configuration is triangular; with two valve groupings, three valves per group. The valves are in two rows, one valve above, approximately opposite the nostril and two directly below. The sealing washers of the valves touch (Figure 4). Three inhalation valves are on one side and three exhalation valves on the other. The direction of flow may be reversed by removing the valves and reinserting them inverted.

Reducing cones have been designed and constructed. These cones fit over the valve group and reduce down to an inside diameter of two inches to allow attachment of flexible hoses.

The face cavity of the mask is contoured to provide minimum dead space and still allow opening and closing of the intake diaphragms.

The valves are made of 1-inch O.D. aluminum rod with a tapped $3/4$ -inch I.D. The valves are $5/8$ -inch long with the bottom $7/16$ -inch threaded, the upper $3/16$ -inch are used to provide attachment and seat for the rubber diaphragm.*

The diaphragms are of standard lightweight rubber produced by Warren E. Collins, Incorporated for use with the J valves.

*Similar in detail to Collins "J" valve made by the Warren E. Collins, Inc., 555 Huntington Ave., Boston 15, Mass.

The valves are sealed by locking washers on either side of the mask. The washers are made from 1 1/2-inch O.D. plastic rod, with tapped I.D. of 1-inch, providing a 1/4-inch sealing surface around each valve (Figure 4).

The actual construction and testing followed a simple plan. First from anthropometric data a face model was constructed, then on this model the mask was formed; the third step was the testing.

Construction of the face model presented little difficulty. Using the data available in the Respiratory Devices Manual and that of Todd and Lindala a line drawing showing general contour and exact pertinent measurements was made (Figures 1 and 2).

This drawing was given to Daniel Sipila, an artist in the Industrial Design Department of Michigan State University.*

Using the drawing, a model face was sculptured in oil base designers clay. Templates and grids were used to insure proper dimensions and symmetry.

Since this face was to serve as a base upon which subsequent portions of the facepiece were to be molded it was necessary to reproduce this face in a harder substance.

*All material manipulations and mask construction techniques were developed and accomplished by Dan Sipila. Basic concepts, sizing, configuration, etc., were original with the author.

A negative reproduction of this clay face was obtained using Ultra Cal 30. Ultra Cal 30 is a material similar to plaster of paris but much harder and less porous. This negative reproduction served as a mold for making copies of the face.

To obtain the negative reproduction the clay model was framed with two-by-four boards, spattered with Ultra Cal 30 to a thickness of 1/8-to 1/4-inches and allowed to stiffen. Then the remainder of the framed area was filled with Ultra Cal containing hemp fibers for reinforcement. When the Ultra Cal hardened the designers clay was removed and the mold cleaned (see Figure 3, A).

The next step was to reproduce the face in Ultra Cal. The mold was sanded as smooth as possible, sprayed with two coats of lacquer sealer and two coats of high gloss lacquer, then waxed and polished, all this to insure a good parting surface.

The mold was then filled with unreinforced Ultra Cal. After hardening the Ultra Cal reproduction was removed, polished and lacquered. This was the face upon which all subsequent modeling was done.

From the same mold two fiberglass reproductions were also made. One served as a base upon which the mask was fastened for airflow resistance testing and the second was kept as a permanent record.

For these copies the mold was prepared in a manner similar to the preceeding casting. Then it was painted with a coating of polyester gell and catalyst mixed in a ratio of 1/100; this coating insured detail in the copy.

Fiberglass cloth was then saturated with a solution of clear liquid polyester and catalyst in a ratio of 2/100 and pressed into place. The layers of cloth were built up to the desired thickness. The entire form was allowed to set until hard and then removed.

Upon the Ultra Cal face the exterior contours of the mask were sculptured using designers clay. The form was smoothed and chilled to insure stability. A frame was placed around one-half of the mask and an Ultra Cal mold was poured using the technique outlined earlier. This pouring was allowed to set and then was removed. The other half was then poured and removed.

The two mask exterior molds were then mounted on individual stands so as to place them in a level, cavity up position. The two molds were then clamped together in proper relationship and the mold was filled with designers clay. With this clay the interior contour of the mask was designed.

When interior design was completed the two exterior molds were spread, carefully splitting the designers clay so half remained with each.

After proper framing, Ultra Cal molds were poured of the interior contours, each half was poured separately. This gave us two complete cavity molds, one of each half of the mask (Figure 3, C). It was now possible to mold the two mask halves and laminate them to obtain a completed facepiece.

The casting material for the final mask was Dow Corning Silastic Rubber RTV589. RTV589 Silastic, supplied as a liquid could be easily poured into the Ultra Cal cavity molds and at room temperatures vulcanizes to a cured rubber in approximately eight hours. Exact mixing and characteristics of the rubber are available from Dow Corning, Engineering Products Division, Midland, Michigan.

For the molding of the mask the silicone rubber was mixed with its catalyst in a ratio of 4/1 by weight. This mixture was evacuated to remove air bubbles.

The two sets of molds were prepared. The inside contour mold was placed on top of the outside contour mold and held in place with springs. RTV liquid was then poured into the mold cavity. The open side of the mold was covered with a sheet of 1/8-inch clear plastic, held in place with dowels and thumb screws (Figure 3, D). Holes were drilled in the plastic to allow excess silastic to seep out. The thumb screws were then tightened to apply pressure insuring proper detail by forcing the silastic into all crevices of the mold.

The other half of the facepiece was poured in a similar manner. The silastic was allowed to cure, then the molds were opened and the pieces removed. The two pieces were placed on a laminating jig designed by Dan Sipila and laminated together forming the completed facepiece, minus suspension system.

Intramask pressures reflecting inhalation resistances were measured at varying rates of flow. The facepiece was mounted on a fiberglass reproduction of the face model, the mask peripheries were sealed completely.

Following the techniques of VanHuss and associates (7), pressure readings were taken by inserting a 3/16-inch I.D. plug into the fiberglass face and connecting this plug to a Sanborn 268A pressure transducer with 3/8-inch inside diameter plastic tubing. Recordings were taken at the various flow rates using a Sanborn 64-500B 132 Strain Gage Amplifier and 60-2000 Twin-Viso Recorder also by Sanborn. Calibrations were made by connecting a water manometer into the system with a "T" tube.

Airflows were obtained for inhalation by cutting out the mouth area of the face model and inserting a sleeve to which a hose was connected. This hose was attached to a vacuum pump and then the pump in turn to a 500 liter Douglas bag. Varying flows were obtained

by regulating the voltage available to the vacuum pump. Flows were taken for one minute, the Douglas bag was then emptied completely and metered according to standard metering techniques to obtain the flow rate in liters per minute.

For exhalation the Douglas bag was filled with a measured quantity of air. The vacuum pump was reversed, then the time necessary to empty the bag completely was measured at various rheostat settings to obtain the exhalation flow rate in liters per minute.

Exhalation resistances were measured in a manner identical to that for inhalation.

Dead space was measured by placing the mask on the Ultra Cal model of the face. All openings and peripheries were sealed except the upper valve orifice when the mask and head as a unit was placed on its side. Water was placed in a graduate. The water was then poured from the graduate into the facepiece cavity, the mask was moved about to insure that there were no air pockets within the cavity.

The amount of water in the graduate after completely filling the cavity, subtracted from the amount in the graduate before filling gave a reasonable approximation of the amount of dead space within the cavity.

TABLE IV
TABLE OF FACIAL MEASUREMENTS

A.	Nasion-Menton	130.1275 mm. or 5.1211 inches
B.	Nasal height	57.3 mm. or 2.1857 inches
C.	Pronasle-Subnasle	20.51 mm. or .8097 inches
D.	Not appropriate	
E.	Nasio-Buccal	78.7125 mm. or 3.0989 inches
F.	Trichion-Gnathion	194.4525 mm. or 7.6556 inches
G.	Inter-Labral Height	19.745 mm. or .7774 inches
H.	Bichelion Diameter	60 mm. or 2.3622 inches
I.	Bigonial Breadth	115.015 mm. or 4.5675 inches
J.	Bizygomatic Diameter	141.17 mm. or 5.5579 inches
K.	Lower nasal breadth	41.192 mm. or 1.6217 inches

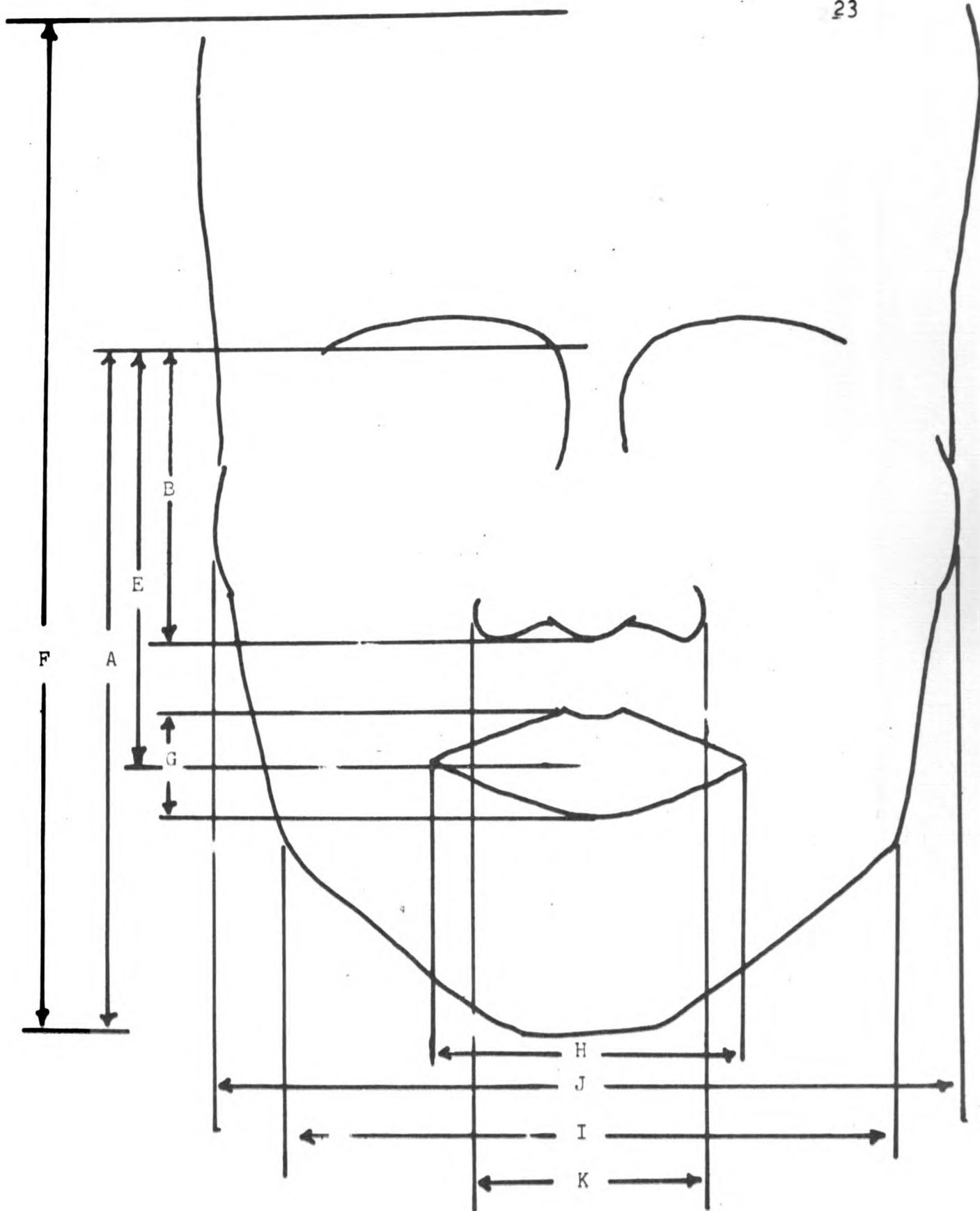


FIGURE 1

FACIAL DIMENSIONS (FULL FACE)

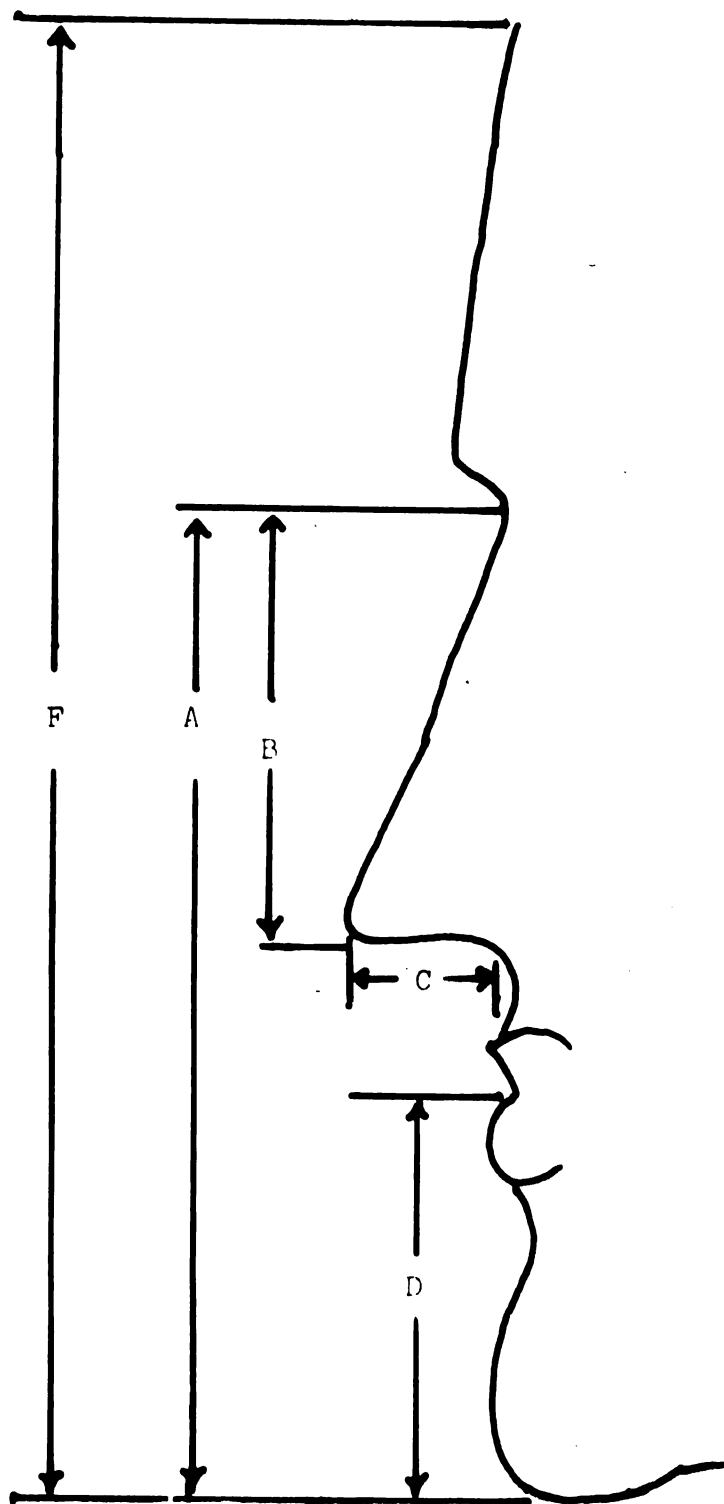


FIGURE 2

FACIAL DIMENSIONS (PROFILE)

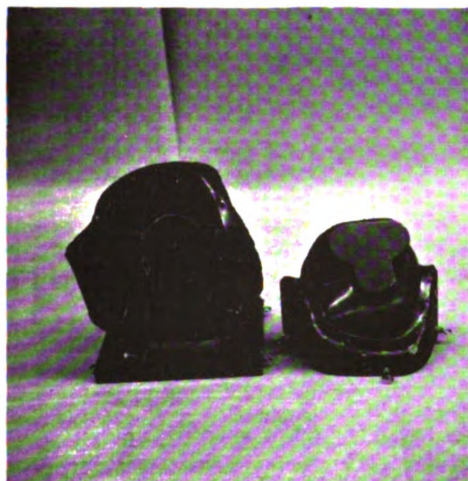
PHASES OF MASK DEVELOPMENT



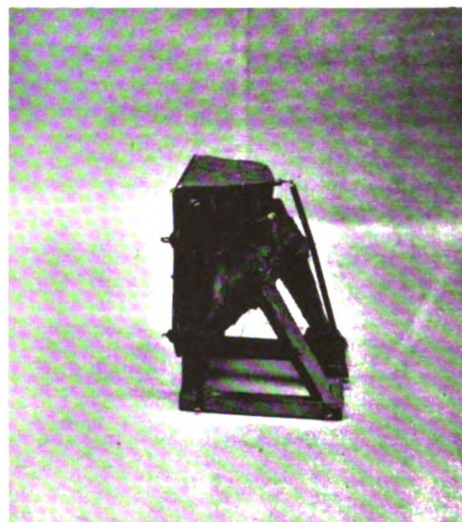
A



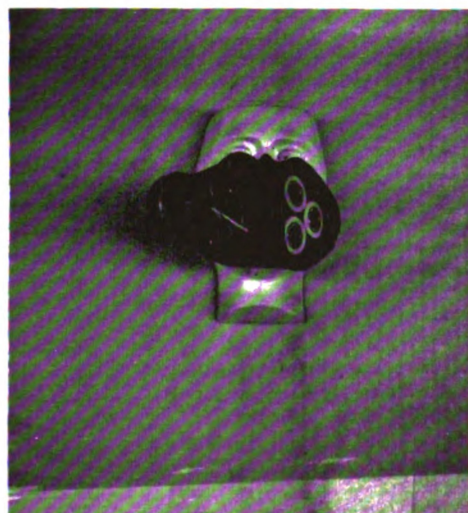
B



C



D



E

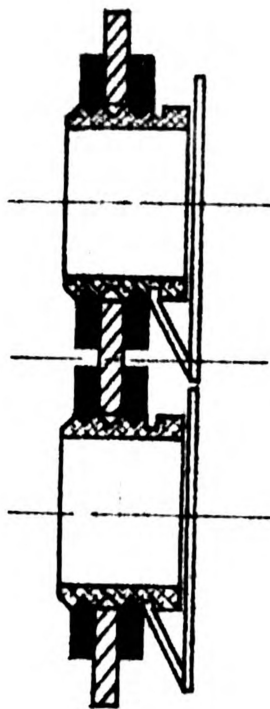


F

FIGURE IV
VALVE ARRANGEMENT AND CROSS SECTION



VALVE GROUP



CROSS SECTION DETAIL

CHAPTER IV

RESULTS

Flow rates were measured and resistances were plotted using rheostat settings from 25 volts to 65 volts in 5 volt increments. Nine exhalation flows were measured. The results are shown in Table II. The air flows range from a low of 102.5 liters per minute to peak flows of 311 liters per minute. Resistance at the peak flow rate was 16.8 millimeters of water.

For inhalation nine settings were also used beginning at 15 and proceeding at five volt increments to 55 volts. Flows ranged from 12.6 liters per minute to 386.8 liters per minute. Resistances varied from 0 millimeters of water at 12.6 liters per minute to 21.6 millimeters at the peak flow rate. The results of the inhalation testing is shown in Table III.

The dead space measure was 187 ml.

Discussion

Chart number one compares the exhalation resistance versus flow rate of the face piece with the results of VanHuss and others (7) in similar tests on the Siebe-Gorman, Franz-Muller and Collins Triple "J" valves.

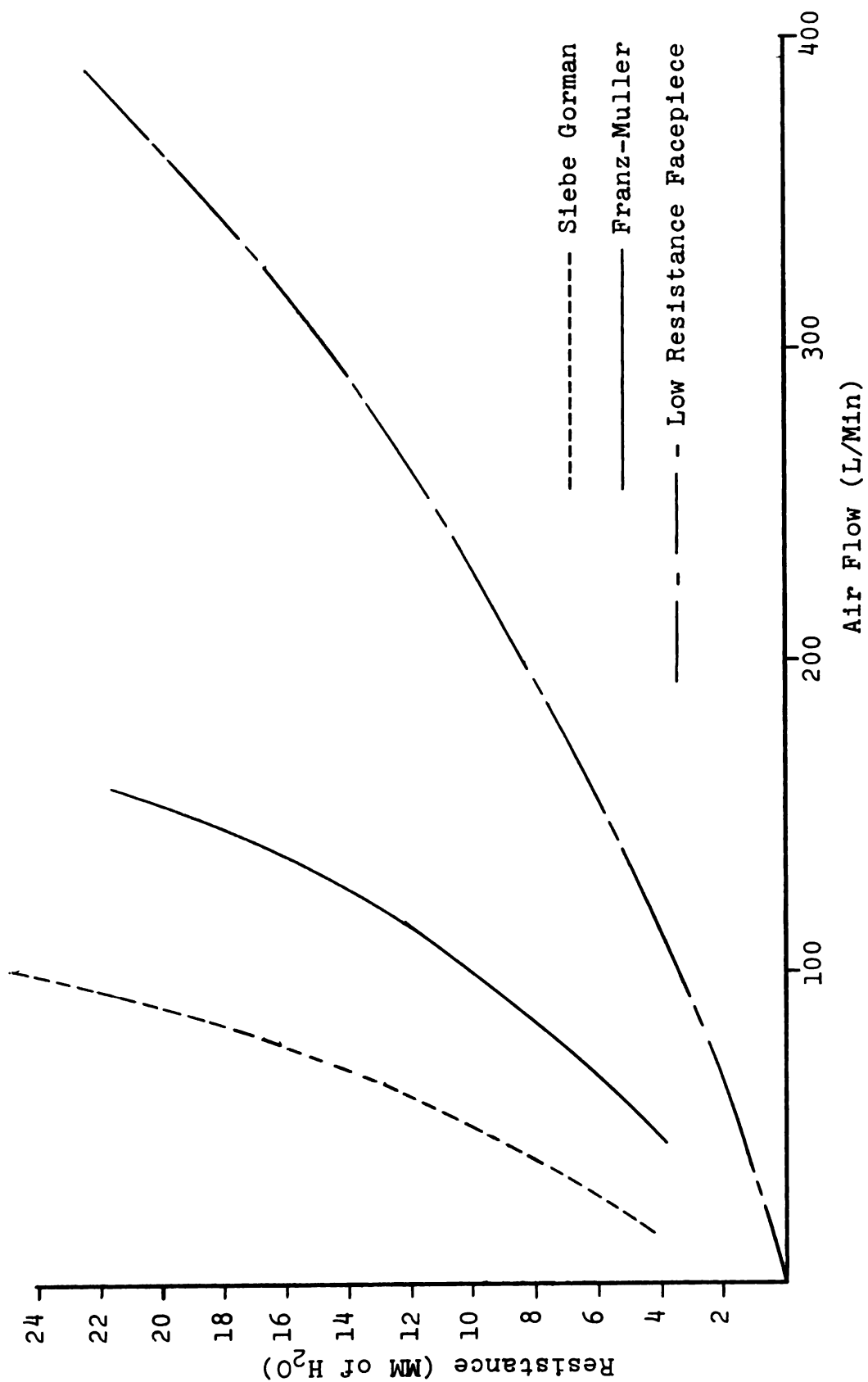


Chart I.--Inhalation

Direct interpretation of this chart must be tempered with the knowledge that in the VanHuss study a hose and Douglas bag were attached to the exhalation outlet.

Even taking into consideration this point it can be seen that the resistance per given flow rate is considerably lower with the face piece. For example at the 100 l/min. level the resistance in the Siebe-Gorman valve is approximately 25 mm. of H_2O , for the Franz-Muller approximately 17 mm. of H_2O and for the low resistance facepiece approximately 5 mm. of H_2O .

As the flows increase the variance is even more dramatic. Interpolating roughly on the chart at the 17 mm. of H_2O level, the flow rate for the Siebe-Gorman was approximately 65 liters per minute, for the Franz-Muller approximately 105 liters per minute, for the Collins Triple "J" approximately 210 liters per minute, for the low resistance face piece approximately 295 liters per minute.

The inhalation measures as shown in Chart 2 can be compared almost directly, for in both the work of VanHuss (7) and this study the inhalation valves were open directly to room air.

Again the differences are most startling at the greater resistances or higher flow rates. At the negative pressure of 20 millimeters of water the Siebe-Gorman shows a flow valve of approximately 90 liters per minute, the

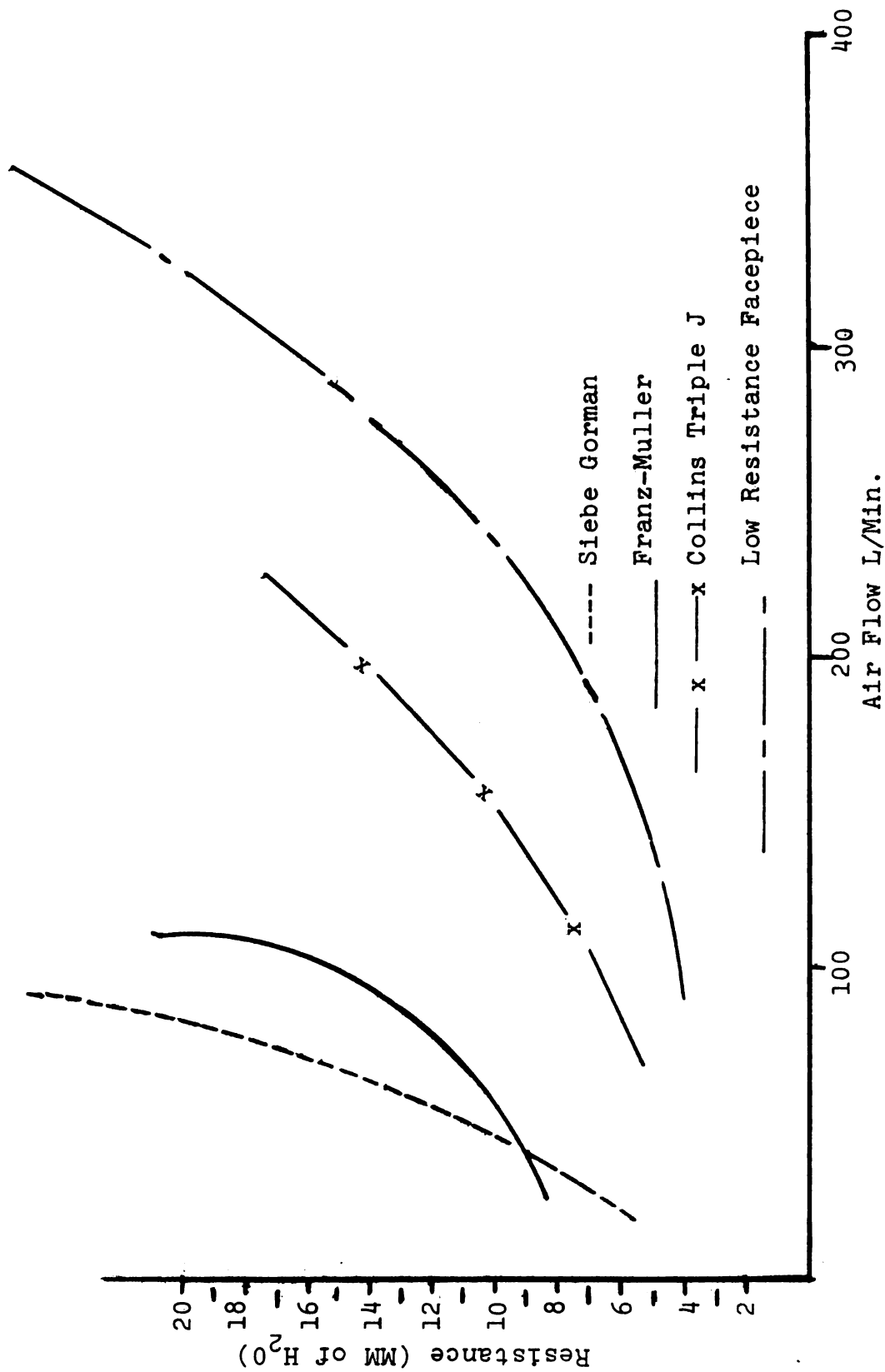


Chart II.--Exhalation

Franz-Muller 155 liters per minute, while the low resistance facepiece has a flow rate of approximately 365 liters per minute.

The Warren E. Collins Company in a recent catalog presents a resistance curve for the Triple "J" valve without hose and Douglas bag.* This allows a more direct comparison of the two pieces of equipment. The chart shows the resistances in centimeters of water.

The inhalation and exhalation resistance reach the 2 cm. level at 350 liters per minute. The facepiece has a resistance of approximately 1.9 cm. (19 mm.) of H₂O for inhalation and 2.4 cm. (24 mm.) of water for exhalation at the 350 liter per minute level.

This more direct comparison indicates that the Collins Triple "J" valve and the low resistance facepiece are almost identical in their resistance to air-flow characteristics.

So it can be said that according to the tests as shown in this study that even for the peak inhalation and exhalation flow rates this facepiece is well within the 20 mm. of water cut off level as quoted by VanHuss (7). Also comparing this mask to the figures in the table by Silverman, shown in Chapter Two, must be

*Warren E. Collins, Inc., 555 Huntington Ave., Boston 15, Mass.

classified as a low resistance facepiece in both categories.

The dead space figures as shown are within the 150-200 ml. minimums set by Silverman as quoted in Chapter Two.

TABLE V
MEAN EXHALATION AIR FLOW AND
INTRAMASK RESISTANCES

Air Flow (L/Min.)	Resistance To Flow (MM. of H ₂ O)
102.5	4.16
134.4	5.54
177.6	6.88
206.5	8.21
244.5	9.6
259.3	10.88
267.7	13.0
276.0	15.0
311.0	16.8

TABLE VI
MEAN INHALATION AIR FLOW AND
INTRAMASK RESISTANCES

Air Flow (L/Min.)	Resistance To Flow (MM. of H ₂ O)
12.6	0.0
87.1	3.2
164.4	6.4
200.8	9.2
249.7	11.2
287.2	13.4
311.2	16.0
338.6	18.4
386.8	21.6

CHAPTER V

SUMMARY AND CONCLUSIONS

The objective of this thesis was to show the development of a low resistance facepiece for collection of expired gases during energy metabolism measurement and within the limits of the tests used prove it a functional piece of equipment.

Step by step the construction method was outlined, beginning with anthropometric measures through all the steps of modeling and molding. The final product was a prototype facepiece molded of RTV589 silastic.

The mask was tested to establish its airflow resistance characteristics. The dead air space with the mask was measured and rated.

Conclusions

1. The inhalation and exhalation resistance measures were such that this mask should be classified as a low resistance facepiece.
2. The inhalation and exhalation resistance measures were lower at every flow rate than other equipment available, designed for the same purpose.
3. The dead air space of 187 ml. was within limits recommended.

Recommendations

1. If this study is repeated greater care should be taken to insure symmetry in the modeling and molding stages.
2. An adjustable head harness, with four attachment points should be designed and laminated to the mask.
3. The mask should be reproduced in a more durable and light-weight latex material.
4. Two additional sizes of the mask should be developed. One reducing the width 5 mm. and the length reduced 11 mm. The other size increasing the width 5 mm. and increasing the length 11 mm., to insure fit for all subjects.
5. Extensive fit and practical usage tests should be run.

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