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Demonstration Project: Putting the Bioastronautics Data Book On Line

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16. Abstract

This report considers the possibilities for prototyping electronic document designs using existing microcomputer software. It describes an initial prototype of a hierarchically structured design that includes both text and graphics from a section of the Bioastronautics Data Book.

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EXECUTIVE SUMMARY

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BIOASTRONAUTICS DATA BOOK PROJECT REPORT

1. Introduction

This report summarizes the work that has been done in response to NASA/STIB TD-85-007: "Requirements for Putting the Bioastronautics Data Book Up On-line." It is organized as follows:

- Understanding of the Problem
- Summary of the Original Response
- Project to Date
    - Electronic Document Design
    - Models Investigated
    - The Demonstration Project
    - Other Investigations.

2. Understanding of the Problem

NASA is considering revising a major NASA reference publication, the Bioastronautics Data Book (BDB). The latest edition was published in 1972, so it is likely that it will have to be completely re-written.

The present BDB is a hybrid between a handbook and a state-of-the-art review. It contains 20 chapters, each covering some aspect of human tolerance for the environmental factors encountered in traveling or working in space, discussions of major body systems affected by space travel, or human performance in the space environment. It includes text, references, tables, and graphics. The graphics are primarily charts, although some are drawings or photographs.

The graphics contain a great deal of information, and many of them are quite complex. Roughly half the pages contain graphics, and a very substantial part of the book is either tables or graphics. There are also a large number of embedded equations, some of which cannot be reproduced by ordinary word processors. Such equations contain multi-line symbols like parentheses or summation or integral signs.

The BDB material is similar in the problems it presents to the patents that PRC is preparing to put online for the Department of Commerce. Any effective treatment must include both ASCII text for machine searching and graphics displays for non-textual information. TD-85-007 asked the NASA STI Facility staff to investigate putting the BDB text and illustrations online. Aspects to be considered include requirements for online access in both text search and question answering modes, including possible uses of the BDB online, hardware, software, and major problems.

3. Summary of the Original Response

In our response to this directive, the Facility staff proposed that investigation of capabilities be broadened beyond text search and text/graphics display of the hard-copy document to consider a product that was truly designed for the automated environment. While such a document might be viewed online through the RECON network, it might also be distributed as a separate database with its own software on compact laser disc. This format would allow many options not available over a network with multi-vendor workstations. We listed a number of new capabilities for consideration and suggested that user reaction would best be tested by prototyping these ideas. The prototyping could be done inexpensively using existing micro-computer software.

In support of our response, we also prepared an example of how new capabilities could be prototyped in the manner suggested. We would be happy to demonstrate this system at NASA's convenience. A hardcopy of the database prepared, which runs under ThinkTank 512 [1] on a 512k Macintosh [2] microcomputer, is included as Appendix A. (The Macintosh was used for reasons explained below. We are, of course, aware of the Facility's IBM orientation, and any continuing investigation would focus on IBM capabilities.) Since we have had no response from NASA about this proposal and the study was not projected for completion within this contract period, we are supplying the work done to date and suspending activity on the project pending further direction.

We wish to mention that the original response to the TD was issued before some clarifications to the background information about graphics capabilities were incorporated. We offer the following clarification. Graphics display units may be painted bit by bit (raster) or they may use directed lines (vector). Almost all display devices are now raster, and it is not very likely that NASA would be displaying the BDB data on any other kind of device. There is a similar distinction between dot matrix printers and plotters.

At the same time there is the question, not of how the data is drawn on the screen, but of how it is stored. It may be stored as a bit map, it may be stored as characters, or it may be stored as objects or vectors, with coordinate descriptions. Objects may be stored and manipulated in this latter form, even if they are created and displayed on raster devices. This feature, for example, distinguishes PC Paintbrush [3] or MacPaint [4], which output bit maps, from, for example, the new MacDraw [5], which is object oriented. Laser printers, such as the Apple Laserwriter [6], will also accept object oriented graphic output.

To illustrate the difference, if one enlarges a box like

```
................
:              :
:              :
:..............:
```

in a bit-mapped system, the result is approximately

```
. . . . . . . . . . . . . . . .
:                             :
:                             :
:                             :
:                             :
: . . . . . . . . . . . . . . :
```

On the other hand, an object oriented graphics package would fill in the empty spaces, producing something like

```
...............................
:                             :
:                             :
:                             :
:                             :
:.............................:
```

Object oriented graphics can also be rotated and allow such things as writing on the diagonal, which is essential for creating maps and many types of charts. They can also be stored and communicated more compactly than bit-mapped images.

The distinction made in the proposal between vector and raster capabilities is more appropriately defined as a distinction between bit-mapped and object-oriented graphics (when dealing with general-purpose computing equipment) so as not to confuse the software data structures with the hardware characteristics.

4. Project to Date

Work was begun in several areas. These include gathering information on electronic document design, preparing a demonstration system, and considering alternative prototyping hardware/software.

4.1 Electronic Document Design

The areas of change involved in the design of electronic documents can be divided into three general headings:

- New types of information
- New ways to search and manipulate information
- New information structures.

4.1.1 New Types of Information

For example, instead of including only a graphic summarizing a set of data, one could also include the raw data so that interested individuals could analyze it themselves. One could also routinely incorporate abstracts, say, for documents in the NASA database or even the text of cited articles in the public domain. In the electronic environment, if the user does not want this detail, the system can be organized so that the extra detail does not intrude, but if he or she wants to use or view these additional features, it is possible to do so.

4.1.2 New Ways to Search and Manipulate Information

Similarly, information may be searched and displayed in new ways. Full-text search features are an obvious enhancement to the usual reliance on back-of-the-book indexes or abstracts. However it is also possible to enhance retrieval by the structure of the documents (as described below), to provide browsing capabilities, and to allow the user to manipulate data through statistical packages, database management tools, or graphics packages.

4.1.3 New Information Structures

Finally, the structure of the text must often be changed. While full-page high resolution screens can duplicate the effect of the document page, environments without this still expensive equipment cannot reproduce document pages as they appear in print. Nor is there any need for such replication for newly created documents that are not being used in conjunction with hard copy. On the positive side, automation makes possible types of access that are prohibited in the paper environment; however, on the reverse side, they make it much more difficult to perceive an information structure, and positive steps must be taken to overcome this limitation.

To see what had been done in the field we did some initial literature searching. Dr. Travis also consulted informally with a friend who is well versed in scholarly publishing and electronic media, and he confirmed that there is not much of substance in the literature. However, we do not feel that the searching done to date is exhaustive.

Most of the literature in electronic publishing deals with issues such as its impact on copyright, on the role and quality of scholarly journals, and on the future of libraries. These topics are interesting, but not of immediate concern here. There are some exceptions, such as articles discussing electronic encyclopedias on videotext [7], the implementation of books in VLSI [8] and the development or use of hypertext packages (see below) [9].

4.2 Models Investigated

Two models for text reorganization are immediately suggested by the literature and reflection. The first is a hierarchical model in which the literature can be organized in such a way that users can control the level of detail they consult; however, the connections within the database are usually only between parent nodes and their children. Another and more flexible model is the network, under which any kind of link between different parts of a database can be pursued. The hypertext concept is an example of a network model. There are a number of problems with network designs at both an intellectual and a housekeeping level, but they have interesting possibilities.

4.3 The Demonstration Project

In order to illustrate these ideas, we prepared a demonstration to show how a document organization could be prototyped. Since the deadline originally suggested to the project team was quite short, we did the simplest thing at hand that could illustrate our point. When we considered a hierarchical arrangement, which seemed the less complex of the possibilities, the program called "ThinkTank", mentioned above, immediately came to mind. It allows the user to enter things in outline format and to expand or contract the depth of the outline viewed or printed at will. In addition, under each heading it allows large (32k maximum) "windows" that can display information.

We selected the Macintosh as the host mini-computer because ThinkTank has an important capability in the Mactintosh version that does not exist in the IBM implementation: it allows graphics to be imported into its database and will display them in a window, just as it displays text. This feature enabled us to capture the graphics (as well as the text) of the selected portions of the BDB very inexpensively, since a fairly high resolution graphics capability is built into the Macintosh and does not require special boards.

4.3.1 Description

An informal survey of the text showed that the first chapter (Barometric Pressure) seemed to represent the range of problems that would be encountered, so the first 16 pages of that chapter were converted. This conversion involved redesigning the database (within the limits of the existing text) and inputting the text and graphics. In order to show a more hierarchical structure, the tables and references associated with each section were physically subordinated to the text. A general pattern was established (as shown in Figure 1) in which an outline caption was set up to reflect a chapter, section, or sub-section heading at whatever outline level was appropriate. Under each caption, the first section was the text, followed by the equations that had to be represented as graphics (if any) and then each table and figure. Finally, the references for each section were input.

Text and tables were keyboarded directly into ThinkTank. Graphics were input by several different methods. The two which worked well enough that their results could be incorporated into the database were to redraw the figures in a business graphics package (Microsoft Chart [10]) or to digitize them from the text (with some special preparation) using a new scanning device that replaces the ribbon cartridge on the Imagewriter printer (Thunderscan [11]) [12]. In some cases the resulting product was enhanced using MacPaint to clean up or add shading to the graph. These two methods are illustrated in Figure 2. Figure 2a shows the graph as created using Microsoft Chart to plot the graph; 2b shows the same chart after it had been enhanced using MacPaint; finally, 2c shows the graph as digitized using Thunderscan. The lettering in this chart was also "touched up" in a few places using MacPaint to make some of the numbers more legible.

1: Barometric Pressure

1.1: Introduction: Barometric Pressure

1.1.1: Organization of the Discussion and Units of Measurement

1.1.2: Figure: Oxygen in Inspired Gas

1.1.3: Table: Equivalent Pressures, Altitudes and Depths

1.1.4: Table: Conversion Table for Barometric Pressure Units

1.1.5: References: Barometric Pressure: Organization and Measurement

Figure 1 - BDB Section Outline

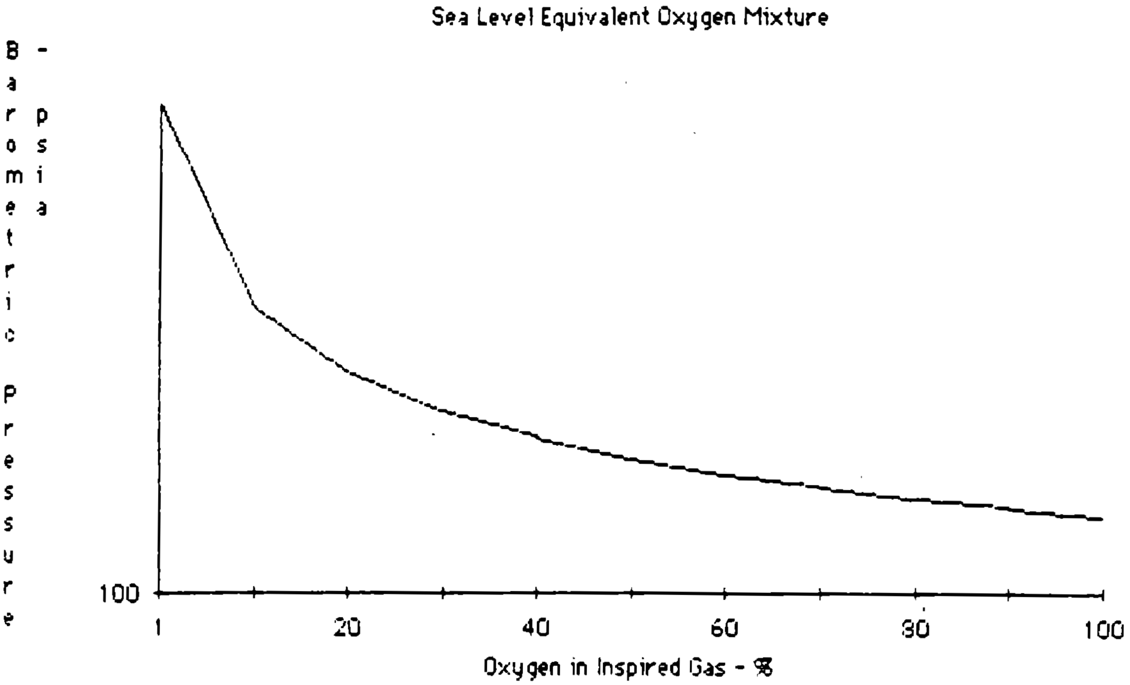

Figure 2a - MacChart Graphic

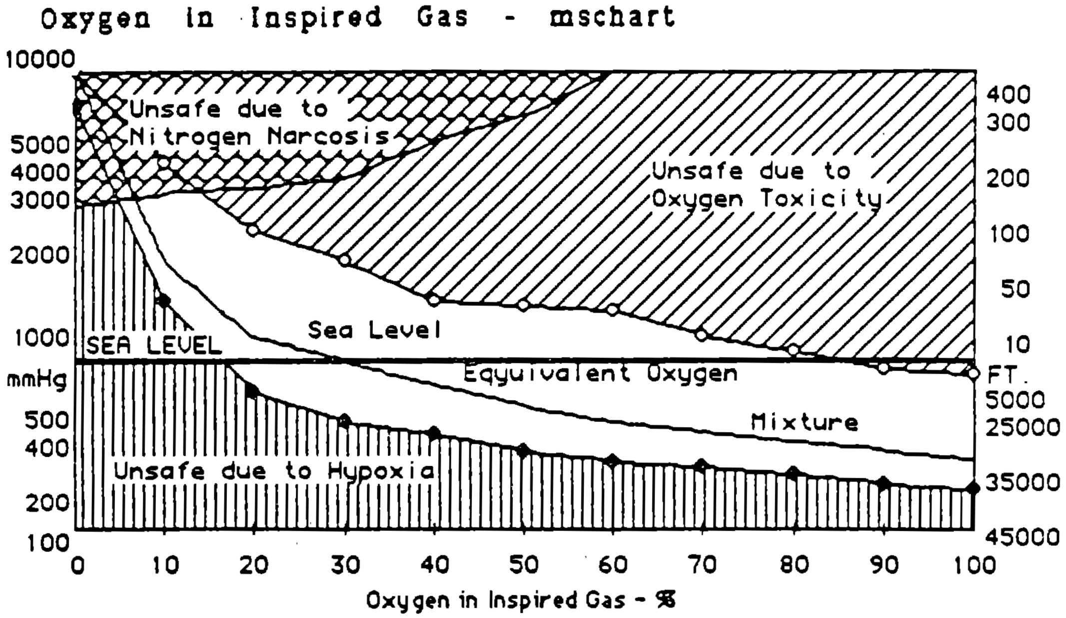

Figure 2b - MacChart Graphic Enhanced Using MacPaint

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OF POOR QUALITY

Oxygen in Inspired Gas - thunderscan

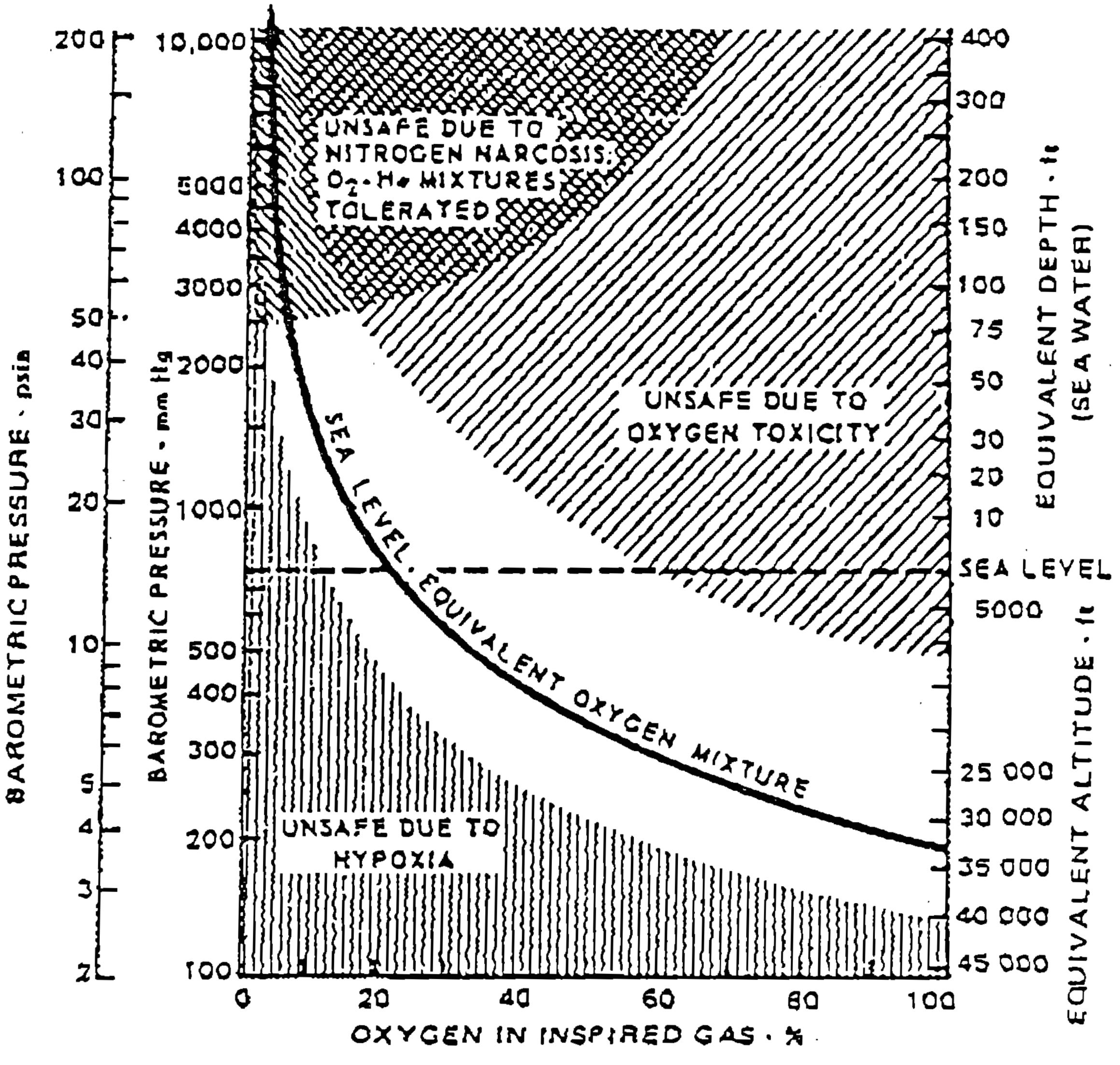


Figure 2c - Scanned Graphic

The resulting database could be accessed in three ways. Firstly, users can browse it in a top-down fashion by displaying the top-level outline (Figure 3a) and expanding the sections of interest until they reach the actual text or graphics (Figures 3b-3e). This method exploits the hierarchical structure of the database.

The second method is string searching. The system has no Boolean operators, but it does allow the user to search for particular words or strings (in the same fashion as most word processors). This search leads immediately to the first instance of the string (whether it is in a caption or a window) with the option of continuing the search to subsequent occurrences.

Finally, Thinktank allows the user to "read" the book, in effect, through the use of the "slide show feature". The slide show will display each window (that is, the text or graphics under each heading) in sequence with the timing set either automatically or under the user's control.

These three methods, then, correspond fairly closely to access via a detailed table of contents, via a back-of-the-book index (which the BDB lacks), or to access by starting at some point and reading or browsing sequentially through the text.

In the course of this exercise, a number of problems surfaced. Some are of general applicability to the design of electronic documents, while others simply concern limitations of present generation computer technology, or, indeed, even of the particular technologies used to prepare the demonstration. The general problems are obviously of most interest.

4.3.2 Problems Uncovered That Have General Applicability

We will discuss two areas of general interest to the design of electronic documents:

- Database Design
- Graphics.

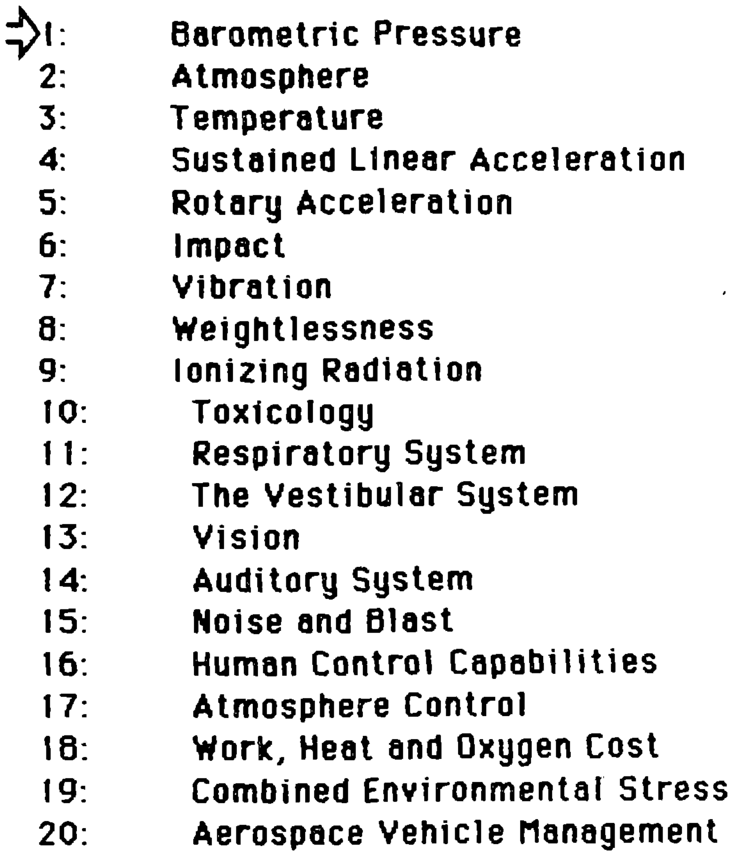
4.3.2.1 Database Design

This exercise showed several areas where design prototyping would be a necessity. Quite apart from the introduction of new functional capabilities, there are formatting problems whose best solution is not readily apparent. We will discuss three such areas:

- Size of Text Units
- Location of References
- Naming and Numbering Conventions.

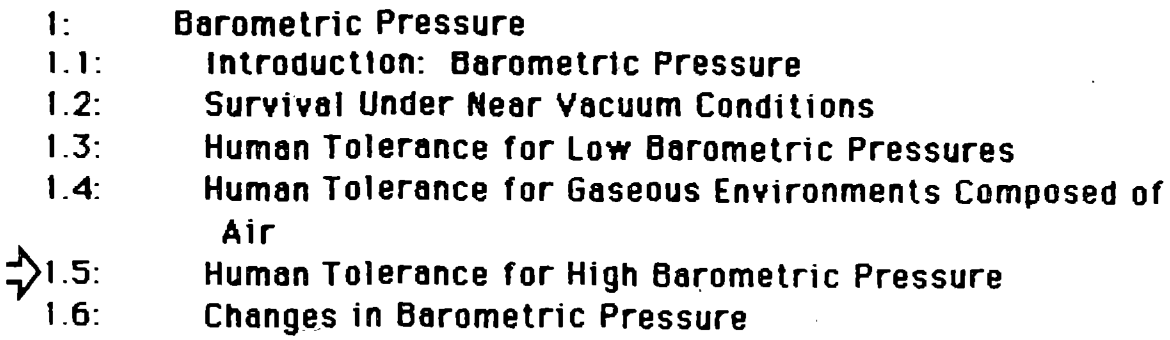
4.3.2.1.1 Size of Text Units

Since no alterations were made to the actual structure of the BDB text, the size of the text units in the sample database varies widely according to the size of the sections that had headings in the text. Some can be shown in a single screen, and others require that the window be scrolled. On one level this system could be used to explore physical ergonomic questions about user reaction to scrolling versus paging. At an intellectual level, the system could be used to explore optimal text unit sizes in light of the tradeoff between the continuity in the presentation of ideas that is possible in large text units and direct access to portions of the text of interest that is facilitated by smaller blocks.



⇨1: Barometric Pressure
2: Atmosphere
3: Temperature
4: Sustained Linear Acceleration
5: Rotary Acceleration
6: Impact
7: Vibration
8: Weightlessness
9: Ionizing Radiation
10: Toxicology
11: Respiratory System
12: The Vestibular System
13: Vision
14: Auditory System
15: Noise and Blast
16: Human Control Capabilities
17: Atmosphere Control
18: Work, Heat and Oxygen Cost
19: Combined Environmental Stress
20: Aerospace Vehicle Management

Figure 3a - Top Level Outline



1: Barometric Pressure
1.1: Introduction: Barometric Pressure
1.2: Survival Under Near Vacuum Conditions
1.3: Human Tolerance for Low Barometric Pressures
1.4: Human Tolerance for Gaseous Environments Composed of Air
⇨1.5: Human Tolerance for High Barometric Pressure
1.6: Changes in Barometric Pressure

Figure 3b - First Level Expansion of Section 1

```
1.5:      Human Tolerance for High Barometric Pressure
1.5.1:      Discussion: Human Tolerance for High Barometric Pressure
1.5.2:      Figure: Calculated Reductions in Maximum Ventilatory Capacity
1.5.3:      Figure: Measured Computed Data for Decreases in Ventillation
1.5.4:      Figure: Mixtures of O2, N2, and He for Sea Level Equivalent
              Density
1.5.5:      Figure: Mixtures of He and O2 for Sea Level Equivalent PO2 in
              Lungs
1.5.6:      References: Human Tolerance for High Barometric Pressure
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Figure 3c - First Level Expansion of Section 1.5

```
 1.5:       Human Tolerance for High Barometric Pressure
 1.5.1:       Discussion: Human Tolerance for High Barometric Pressure
 1.5.2:       Figure: Calculated Reductions in Maximum Ventulatory Capacity
 1.5.2.1:        Figure: Keywords
→1.5.3:       Figure: Measured Computed Data for Decreases in Ventullation
 1.5.3.1:        Figure: Keywords
 1.5.4:       Figure: Mixtures of O2, N2, and He for Sea Level Equivalent Density
 1.5.4.1:        Figure: Keywords
 1.5.5:       Figure: Mixtures of He and O2 for Sea Level Equivalent PO2 in Lungs
 1.5.5.1:        Figure: Keywords
 1.5.6:       References: Human Tolerance for High Barometric Pressure
```

Figure 3d - Full Expansion of Section 1.5 Headings

1.5.3: Measured Computed Data for Decreases in Ventilation

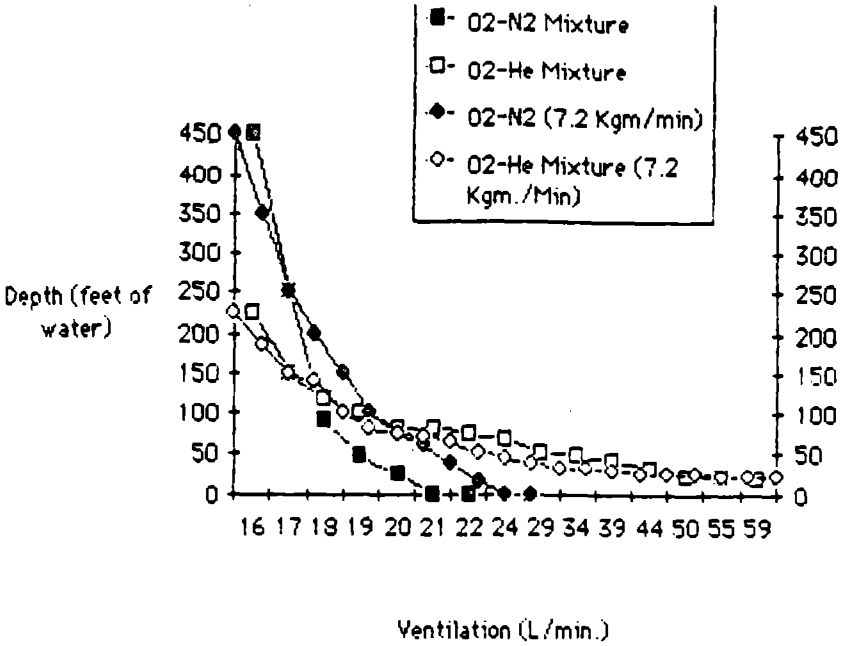

Figure 3e - Graphic Window Under Caption for Section 1.5.3

The optimal solution to this latter tradeoff is also considerably influenced by the access methods used for the text. For example, if a software package does not highlight the location in the display of a string that has matched a search request, then small text units are desirable so the user can find the match easily. However, on the other hand, the user needs enough text that it is likely he will find what he needs to know without having to call up additional information.

Similarly, if the text is being accessed through a detailed table of contents, then the micro-structure of the text is very important. It is important that all identifiable topics discussed, even at a paragraph level, be labeled. Often authors in printed works do not give headings at that level of detail. For example, we had to invent section names for the introductory paragraphs coming immediately after major headings in the BDB chapter we converted.

Finally, there will usually be other extraneous constraints such as record size. In the case of this demonstration system, it turned out that it is not possible to scroll text in ThinkTank in slide show mode, so this type of browsing requires breaking the text into screen-size chunks. The potential utility of this "reading mode" feature was not realized, however, until after the data had been input, so the database is, in fact, not optimally designed for this package.

Generally, because of difficulties in showing structure and cross referencing, texts written for electronic presentation may need to be chunked into more independent units, even if the units contain more repetition than would be tolerable in a printed document. The medium is not ideally suited to lengthy and intellectually complex discussions in text form, whatever its potential power may be to present ideas through graphics or interactive instruction.

4.3.2.1.2 Location of References

At a more mundane level, it seems reasonable to associate the references with the text that references them (rather like bottom-of-the page footnotes) rather than grouping them into chapter-level reference lists. On the other hand, the chapter bibliographies per se may be useful in that form, so perhaps both listings should be included.

For instance, in the original database design, the references mentioned in the graphics titles were associated with the graphic itself, not with the reference list for the section that incorporated both the text and the graphic. However, when the database was complete, this chopping up and layering of references seemed extreme, and the graphic references were put back in with the general references for the text of the section. This area is obviously one in which user reactions should be solicited.

4.3.2.1.3 Naming and Numbering Conventions

When one designs an electronic database, an immediate problem is how to label and identify the text and graphics units. Conventionally, when one is simply viewing online a document that also exists in hard copy, the system may allow reference by page number, and such concepts as "Figure 1" are not totally meaningless. However, when the text layout does not correspond to a hardcopy document and the access is not necessarily sequential, the problem is more difficult.

In a package that could display paragraph numbers, one could use a hierarchical numbering scheme for access. (Unfortunately, while ThinkTank prints these numbers, it does not display them on the screen.) Similarly, one could display and search by frame numbers. This method is very common and is frequently seen even in printed products, such as programmed instruction texts. References to such entities as "Figure 1" are quite meaningless in this kind of framework.

If the ThinkTank database were to be redone, some thought should probably be given to numbering the windows as frames. In this case it was not done, so all references to figures, tables, sections, and chapters had to be changed to give the title of the text unit in question rather than a brief citation. This type of reference is awkward in the text, but at least the heading can be found through the outline or through a string search. User reaction to various conventions could be tested.

4.3.3 Graphics

The problem with graphics is that they are not text searchable. They can be displayed, but the text information on them is in facsimile form and cannot be accessed. The graphics, therefore, have to be manually indexed. In this case, a separate heading was set up for each graphic, and under each heading was a caption for the graphic keywords. In this case the text was fairly much just lifted from the table stubs and plot labels with attention to not breaking phrases over a line. (The string search mode is usually sensitive to carriage returns.) It had to be done in this way because ThinkTank (and other micro packages) do not allow text and graphics to be combined in a single frame; however, there are products like the Wang Pix system that have this capability. In such a system the indexing for the graphic could be put in the same display frame as the graphic itself and eliminate the problem of the user finding the indexing, but not the picture when they conduct a keyword search.

4.4 Other Investigations

In addition to the hierarchical database demonstration discussed above, investigation was begun on several other subproblems related primarily to prototyping, rather than to putting up the actual new edition of the BDB. These included the following areas:

- Data Conversion
- IBM Software
- Data Retrieval.

4.4.1 Data Conversion

Given how old the current edition of the BDB is, it seems unlikely that is would be very valuable to convert it to machine readable form solely for purposes of producing the new edition, although chapter authors should be consulted. The conversion problem, then, only affects whatever additional parts of the text might be used for prototyping. Re-keying seems a perfectly adequate solution for the text involved; however, keying into a word processor that produces ASCII text that can be easily transported to more than one system or program seems more desirable than direct entry into packages like ThinkTank, where transferring it anywhere else is inconvenient.

Converting the graphics is a more difficult problem. If they are recreated in a graphics package, then they will display on a standard monitor. The problem is the considerable limitations of the present generation of personal computer graphics packages. They cannot even approximate highly complex graphics like BDB Figure 3-19 (report Figure 4). Also, for example, Microsoft Chart has no way to change the shape of the graphic, so a graphic whose long dimension should have been vertical, has the long dimension horizontally instead (compare Figures 2b and 2c).

The only way complex graphics can be input on a personal computer is by scanning. This process can be done with fair results very cheaply on the Macintosh. Figures 5 and 2c show scanned graphics. In Figure 5, the top 1/2 inch was "cleaned up" using MacPaint. This cleaning up could be done for the whole chart without very much effort. The $2000 Macintosh has fine enough resolution to display these images almost as legibly as they are reproduced here by the laser printer, and the scanning device only costs $300. We did not finish exploring the scanning problems for the PC, but we believe that a similar capability will be much more expensive, possibly as much as another $5000 or $6000 in addition to the cost of the micro-computer.

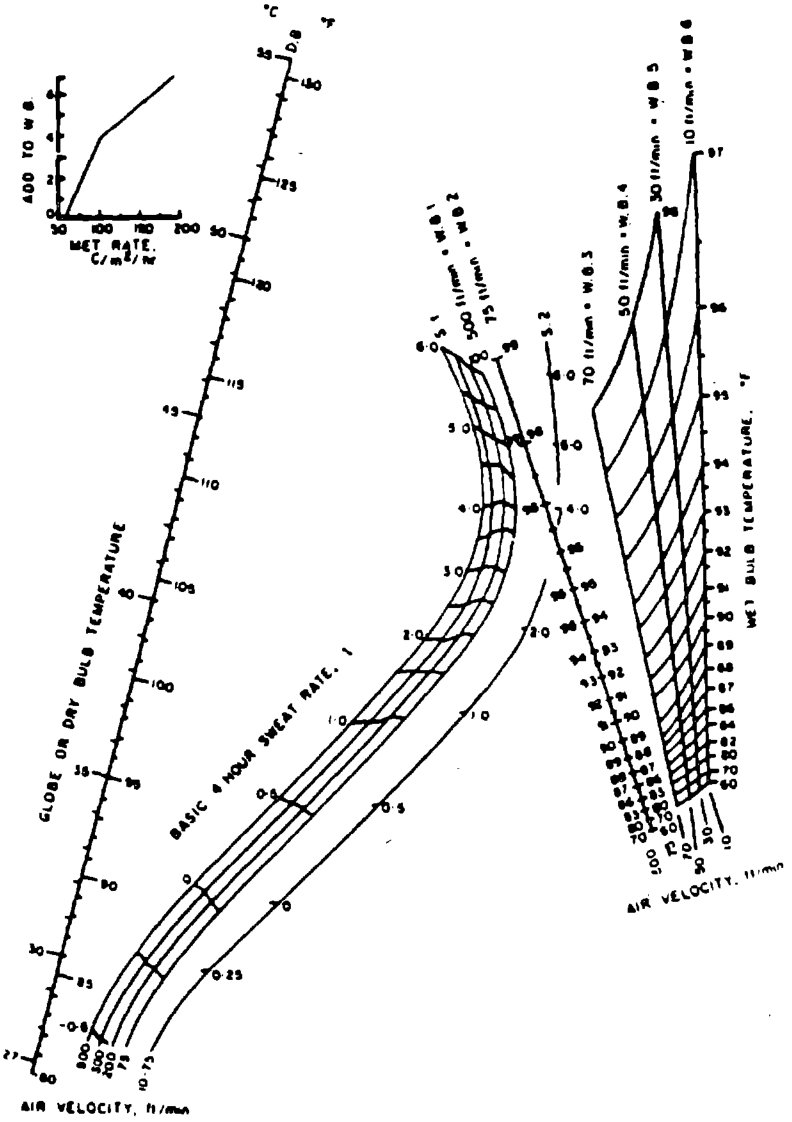

Figure 4 - Complex Graphic from the BDB

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Table 1–1
Equivalent Pressures, Altitudes and Depths

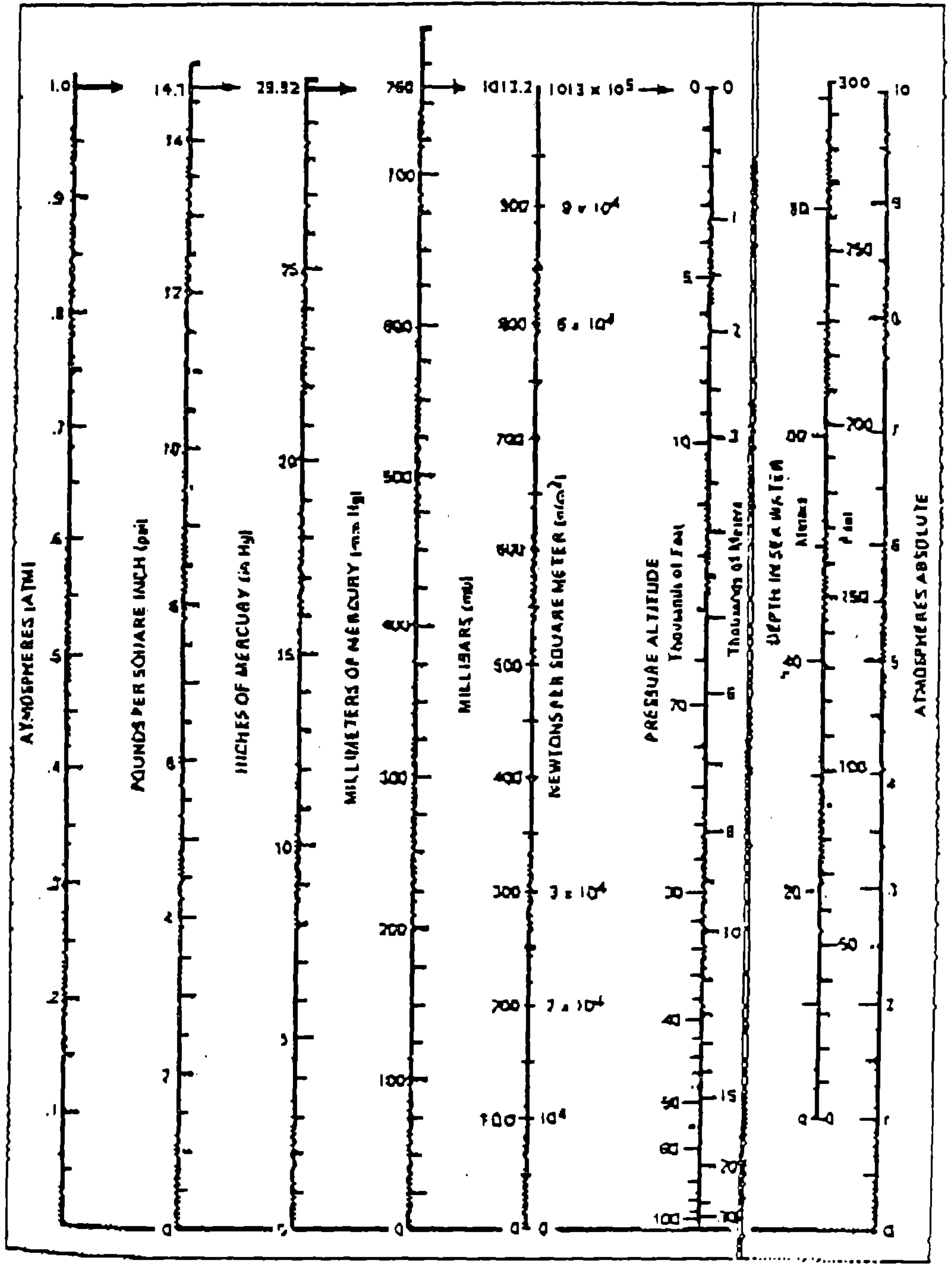

Figure 5 - Scanned Graphic

We also tried two other methods unsuccessfully. The first was drawing graphics in MacPaint (as opposed to having the computer generate the plot). While free-hand drawing may be possible, we could not produce usable results. Using a business graphics package to do the basic plot worked much better. The other method tried was digitizing from video rather than paper. There are various inexpensive devices that will convert data from video cassette images, but the resolution was far too low for this purpose.

We should also mention that scanning was not possible directly from the unenhanced text. Firstly, all vertical and horizontal lines must be as square on the page as possible. If the image is on the diagonal or wavy, it will not scan properly. Unfortunately, if one tries to scan directly from a xeroxed copy from a thick book like the BDB, the lines are likely not to be square. Also it helps to enlarge the graphic as much as possible. For these reasons, the graphics to be scanned were first enlarged and re-aligned. After this preprocessing, the results were quite gratifying, considering how inexpensive the scanning device is.

4.4.2 IBM Software for Prototyping

Some thought was given to prototyping a network model on the PC. Framework [13], for example, appears to have some interesting capabilities for this purpose since it not only can display text in outline form with windows (like ThinkTank), but it can also accept charts and spreadsheets generated by other parts of the package as windows in its outline file. Finally, it has some capability to link windows, the feature that might allow it to prototype a network base.

Another interesting possibility is Savvy [14], a DBMS which has a primitive natural language front-end and enough programming power associated with it that it might be possible to do a network model. We have not definitely ascertained that it could support this application.

4.4.3 Data Retrieval

There are several ways in which direct data retrieval from a product like the BDB might be supported. The most feasible is to put data now in tables and graphs into a spread sheet or DBMS format that could be accessed by a query language, statistical package, or graphics package, such as that in Framework or in Microsoft Chart. Some data might also be put into an expert system package like Personal Consultant [15].

If the data were in a mainframe DBMS such as ADABAS, it could be accessed by a natural language query language [16] such as Intellect or IRUS, a similar Bolt, Beranek, Newman (BBN) product being introduced this fall. This system includes the very powerful RUS parser, but the commercial version is DBMS oriented. BBN will have to build the lexicons. The system is being issued with a 500 word general vocabulary and a 1000 word lexicon for personnel records applications.

Neither of these two query language products, however, will do more than word-search text and the automatic Boolean capabilities will not function properly for this type of application. Natural language question answering from a text database is not yet feasible for a database of the size and complexity of the BDB. NASA could probably achieve comparable results by incorporating the lexical dictionary into the RECON interface.

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1. ThinkTank 512 is a trademark of Living Videotext, Inc.

2. Macintosh is a trademark of Apple Computer, Inc.

3. PC Paintbrush is a trademark of Z-Soft Corporation.

4. MacPaint is a trademark of Apple Computer, Inc.

5. MacDraw is a trademark of Apple Computer, Inc.

6. Laserwriter is a trademark of Apple Computer, Inc.

7. Cook, Peter R., "Electronic Encyclopedias," *Byte*, v. 9, no. 7 (July 1984), pp. 151-170.

8. Murray, John and Kenneth J. Klingenstein, "The Architecture of an Electronic Book," *IEEE Transactions on Industrial Electronics*, v. IE-29, no. 1 (February 1982), pp. 82-91.

9. Gregory, Roger, "XANADU: Hypertext from the Future, " *Dr. Dobb's Journal*, no. 75 (January 1983), pp. 28-35.

10. Microsoft Chart is a trademark of Microsoft Corp.

11. Thunderscan is a trademark of Thunderware, Inc.

12. Imagewriter is a trademark of Apple Computer, Inc.

13. Framework is a trademark of Ashton-Tate.

14. Savvy is a trademark of Excalibur Systems.

15. Personal Consultant is a trademark of Texas Instruments.

16. Travis, Irene L. *Applications of Artificial Intelligence to DBMS and Storage and Retrieval Interfaces.* Technical Report TR-RD-85-2. McLean, VA: Planning Research Corp., May 1985.

APPENDIX A: THINKTANK 512 DATABASE PRINTOUT

Note: Due to some problems with the text editing capabilities in ThinkTank 512, not all windows print in proper format, although they do display properly on the screen. In particular, tables do not print in proper alignment, nor do some of the bibliographic entries.

CHAPTER 1

BAROMETRIC PRESSURE

By

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1.1: Introduction: Barometric Pressure

1.1.1: Organization of the Discussion and Units of Measurement

Physiological studies of pressure effects have been conducted for over a century. Still, many facets of the problem have been incompletely explored. It is known that if man is supplied with an apprpriate gas mixture, he can survive considerable periods of exposure to a wide range of barometric pressures (Figure: Oxygen in Inspired Gas). Man's ultimate tolerance limits for high and low barometric pressure are not known, however. Likewise it is not known whether the gas mixtures required for such exposures are in themselves toxic.

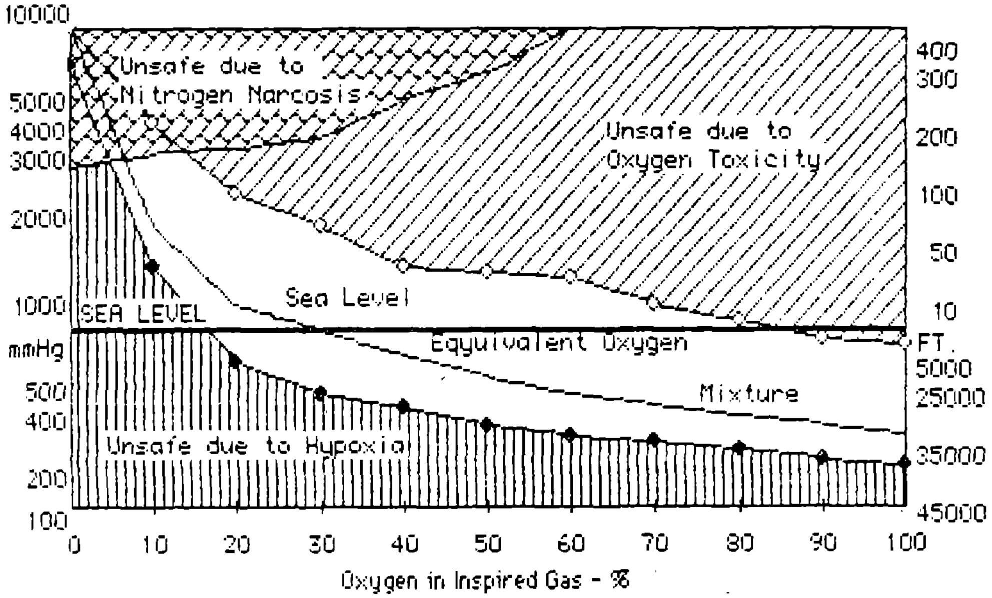
Barometric Pressure describes the effects of alterations in barometric pressure describes the effect of alterations in barometric pressure on human beings. The subject is of considerable importance in both aerospace an dunderwater exploration, although the former area is given primary emphasis here. The effects of barometric pressure as such must be differentiated form the effects of change in pressure. In the latter case, our knowledge is more complete. Abrupt and controlled changes in pressure can be produced in compression and decompression chambers, shock tubes, wind tunnels, and the like.

Increases in barometric pressure are experienced most commonly during descents through the atmosphere and underwater diving. High dynamic (unbalanced) pressures are encountered during escape from aircraft. Still higher pressures occur in the vicinity of explosions. Decreases in pressure are encountered during ascents through water or the atmosphiere or during depressuization of an aircraft or space vehicle. The physical effects of these changes are considered in this chapter. Exposure throughout the tolerable range of pressure is discussed first, followed by desciptions of the effects of increases, then decreases in barometric pressure.

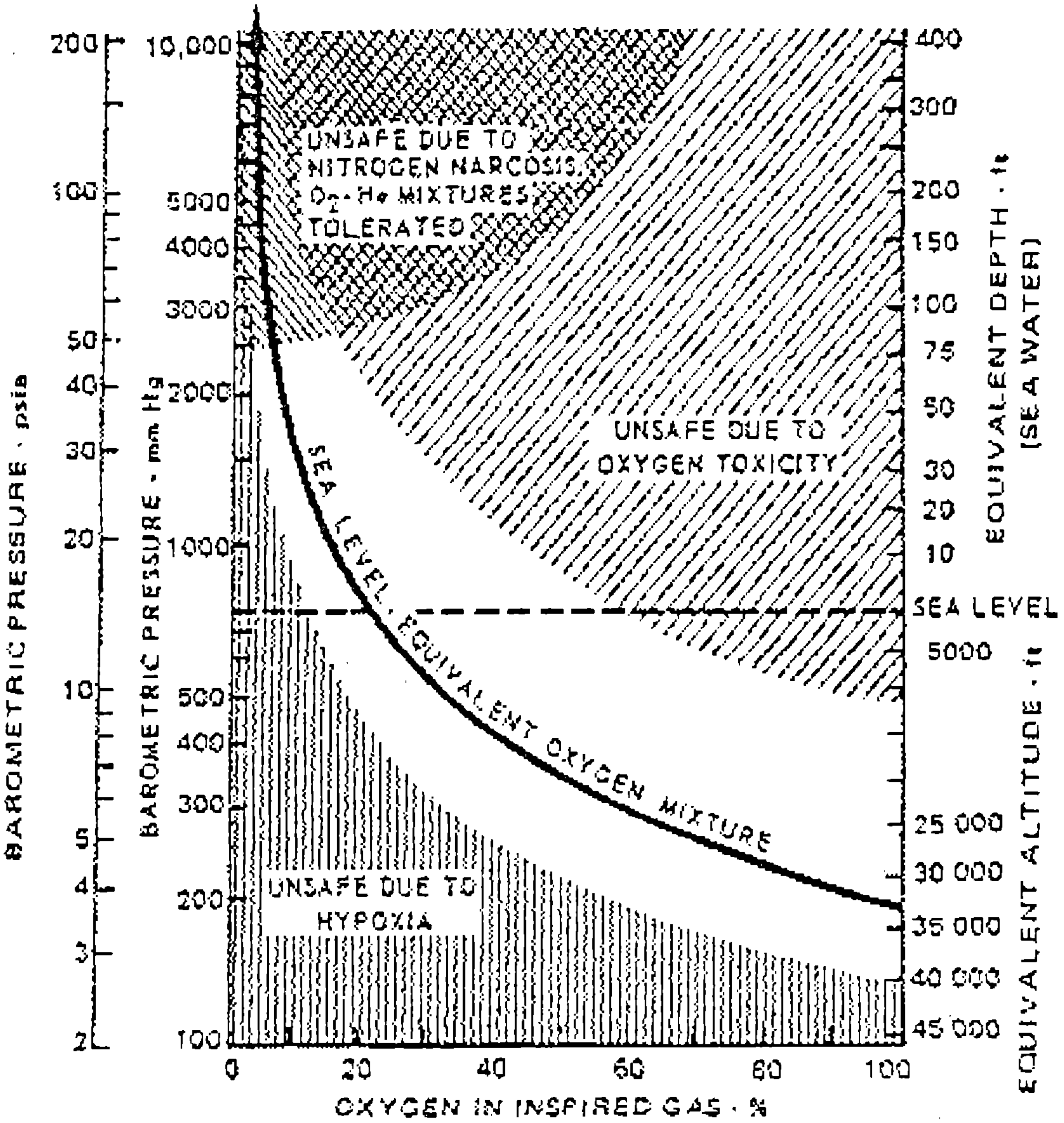
In view of the multiplicity of systems for describing pressure, the following tables have been included as an aid to the reader wishing to convert pressure terms from one notational system to another. The tables "Equivalent Pressure, Altitudes and Depths" and "Conversion Table for Barometric Pressure Units" contain many, though not all, of the units of pressure measurement in common use. The preferred units for scientific use are those of the new International System nationale), which 6□9□AStandarrecommentds Newtons per square meter but accepts the bar and millibar for common usage. The inch of mercury and millibar are widely used in aviation. Millimeters of mercury are in common biomedical use in the United States and elsewhere. In diving medicine, the atmosphere is commonly used. Note in "Equivalent Pressure, Altitudes, and Depths" that 0 feet of water equals 1 atmosphere. The increase of pressure with increasing depth in sea water is roughly 1 atm for each 33 feet. Since air in compressible, the altititude scale is logarithmic. The data for altitude are from the U.S. Standard Atmoshpere, (1954).

1.1.2: Figure: Oxygen in Inspired Gas

1.1.2.1: Oxygen in Inspired Gas - mschart



1.1.2.2: Oxygen in Inspired Gas - thunderscan



1.1.2.3: Figure: Keywords

barometric pressure, above sea level, below sea level
toleration, humans, gas mixtures, O2, PO2, lungs, psia,
mm Hg, ft, equivalent depth, sea water, equivalent altitude, unsafe, nitrogen narcosis,
oxygen toxicity,
hypoxia

1.1.3: Table: Equivalent Pressures, Altitudes and Depths

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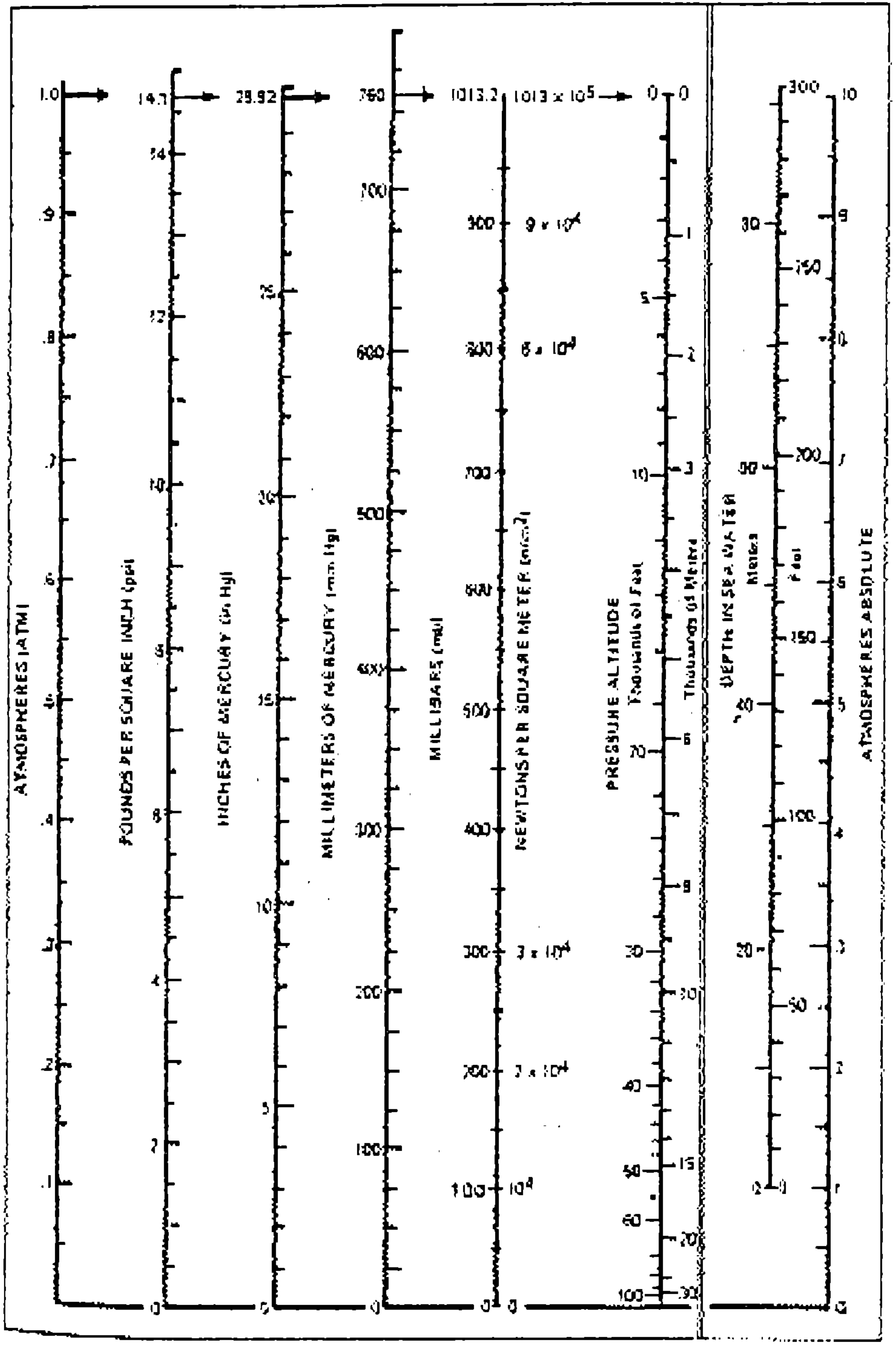
1.1.3.1: Table 1-1 Graphic

Table 1-1
Equivalent Pressures, Altitudes and Depths



1.1.3.2: Table 1-1 Keywords

Equivalent pressure, altitudes, depths, Atmospheres,
Pounds per square inch, atm, psi, millibmeters of mercury
mm Hg, millibars, mb, Newtons per square inch, n/m2, pressure, althitude, depth in sea water,

atmospheres absolute

1.1.4: Table: Conversion Table for Barometric Pressure Units

Conversion Table for Barometric Pressure Units

	atm	n/m*2	bars	mb	kg/ cm*2	gm/ cm*2	mm Hg	in. Hg	lb/in2
1 atm =	1	1.013 x10*5	1.013	1013	1.033	1033	760	29.92	14.70
1 n/ m*2 =	.9869x 10*-5	1	10*5	.01	1.02x 10*-5	.0102	.0075	.2953x 10*-3	.1451x 10*-3
1 bars=	.9869	10*5	1	1000	1.02	1020	750.1	29.53	14.51
1 mb =	.9869x 10*-3	100	.001	1	.00102	1.02	.7501	.02953	.0145
1 kg/ cm2 =	.9681	9807x 10*5	.9807	980.7	1	1000	735	28.94	14.22
1 gm/ cm2 =	968 1 x10*-3	98.07	.9807	.9807	.001	1	.735	02894	.0142
1 mm Hg =	.001316	133.3	.001333	1.333	.00136	1.36	1	.03937	.0193
1 in. Hg =	.0334	3386	03386	33.86	.03453	34.53	25.4	1	.4910
1 lb/ in*2 =	.06804	6895	.06895	68.95	.0703	70.3	51.70	2.035	1

1.1.5: References: Barometric Pressure: Organization and Measurement

United States house of Representatives Select Committee
on Astronautics and Space Exploration. Space
Handbook: Astronautics and its applications.
House Document No. 86 First Session, 86th Congress.
Washington, D.C.: U.S. Government Printing Office,
1959.

1.2: Survival Under Near Vacuum Conditions

1.2.1: Discussion: Survival under Near-Vacuum Conditons

The vapor pressure of water at a body temperature of 37 degrees C is 47 mm Hg (0.9 psia). Since the human body is largely composed of water, exposure to barometric prssure much below 47 mm Hg absolute leads rapdily to vaporization of body fluids, a process known as ebullism. That this phenomenon does not occur precisely at 47mm Hg is due to some degree of counterpressure exerted by the skin and connective tissues and blood vessels.

Some degree of consciousness will problaby be retained for 9 to 11 seconds (see Hypoxia). In rapid sequence thereafter, paralysis will be followed by generalized convulsions and paralysis once again. During this time, water vapor will form rapidly in the soft tissues and somewhat less rapidly in the venous blood. This evolution of vapor will cause marked swelling of the body to perhaps as much as twice its normal volume unless it is restrained by a rpessure suit. (It has been demonstrated that a properly fitted elastic garment can entirely prevent ebullism at pressures as low as 15 mm Hg absolute [Webb, 1969, 1970]. Heart rate may rise intially but will fall rapidly thereafter. Arterial blood presssure will also fall over a period of 30 to 60 seconds, while venous pressure rises due to distension of the venous system by gas and vapor. Venous pressure will meet or exceed arterial pressure within 1 minute. There will be virtually no effective cirulation of blood. After an initial rush of gas from the lungs during decompression, gas and water vapor will contiue to flow outward through the airways. this continual evaporation of water will cool the mouth and nose to near-freezing temperatures; the remainder of the body will also become cooled, but more slowly.

Cooke and Bancroft (1966) reported occasional deaths in animals due to fibrillation of the heart during the first minute of exposure to near-vacuum conditions. Ordinarily, however, survival was the rule if recompresion occured within 90 seconds. The hearts in the studies tolerated even repeated decompression well (Cooke and Bancroft, 1966), although it is by no means certain that the human heart will be as tolerant. Once heart action ceased, death was inevitable, despite attmpts at resuscitation. During recompression, as the absolute pressure exceeded about 50 mm Hg (1 psia), a dramatic reduction in the swelling was demonstrated. Breathing usually began spontaneously, the time being dependent on the duration of exposure at minimum pressure. Heart rate and blood pressure rose to fairly hgih levels, then gradually returned toward normal. There was suggestive evidence in the Cooke and Bancroft studies that denitogenation prior to exposure, and recompression with 100 percent oxygen, both improved recovery time and decreased mortaility. Neurological problmes, including blindness and other defects in vision, were common after exposures (see problems due to evolved gas), but usually disappeared fairly rapidly.

It is very unlikely that a human suddenly exposed to a vacuum will have more then 5 to 10 seconds to help himself. If immediate help is at hand, although one's appearance and condition will be grave, it is reasonable to assume that recompression to a tolerable pressure (200 mm Hg, 3.8 psia) within 60 to 90 seconds could result in survival, and possibly in rather rapid recovery. There is, of course, no guarantee of a successful outcome; some animals have died within seconds of decompression and a few others have had severe, lasting central nervous system damage (Casey, Bancroft, & Cooke, 1966).

Barometric pressures below those at which adequate blood and tissue oxygenation can be maintained (about 190 mm Hg, 3.7 psia) must be considered hostile for more than brief exposures without proper protective equiment (see Atmosphere); those below about 100 mm Hg (1.9 psia) must be considered hostile for any exposure. Pressure much below 5 mm Hg cause almost immediate failure of the circulation and total anoxia and must be considered lethal if sustained for more the 60 to 90 seconds.

1.2.2: References: Survival under Near-Vacuum Conditions

Bancroft, R.W., & Dunn, J.E. Experimental animal decompressions to a near vacuum environment. USAF SAM TR-65-48A. School of Aviation Medicine, Brooks Air Force Base, Texas, 1965.

Casey, H.W., Bancroft, R.W., & Cooke, J.P. Residual pathologic changes in the central nervous system of a dog following rapid decompression to 1 mm Hg. USAF SAM TR-66-203. School of Aviation Medicine, Brooks Air Force Base, Texas, 1966.

Cooke, J.P., & Bancroft, R.W. Some cardiovascular responses in anesthetized dogs during repeated decompressions to a near vacuum. USAF SAM TR-66-88, School of Aviation Medicine, Brooks Air Force Base, Texas, 1966.

Cooke, J.P., Cain, S.M., & Bancroft, R.W. High venous pressures during exposure of dogs to near vacuum conditions. USAF SAM TR-67-257. School of Aviation Medicine, Brooks Air Force Base, Texas, 1967.

Cooke, J.P., Fife, W.P., and Bancroft, R.W. Comparative caridovascular repsonses of baboons and dogs to near vacuum pressures. USAF SAM TR-68-44. School of Aviation Medicine , Brooks Air Force Base, Texas, 1968.

United States House of Representatives Select Committee on Astronautics and Space Exploration. Space handbook: Astronautics and its applications. House Document no. 86. First Session, 86th Congress. Washington, D.C.: U.S. Government Printing Office, 1959.

1.2.2.1: Abstract: Cooke, Fife, and Bancroft, 1968

This experiment compared ......

NASA/STAR.....

1.3: Human Tolerance for Low Barometric Pressures

1.3.1: Discussion: Human Tolerance for Low Barometric Pressures

The partial pressure of water vapor in the lungs is about 47 mm Hg (0.9 psia). The normal partial pressure of carbon dioxide in the lungs ranges from 35 to 45 mm Hg (0.7 to 0.9 psia). A partial pressure of oxygen in the lungs of about 100 mm Hg (1.94 psia) will maintain essentially complete oxygen saturation of arterial blood. A total baromentric pressure of 190 mm Hg (3.66 psia), then, will support a human being if his environment consists of pure oxygen. It should be noted, however, that this figure leaves little room for further reductions such as would occur in the face of space cabin or pressure suit leaks, temporary failures of gas supply, dilution of the atmosphere by nitrogen or other inert gases, or carbon dioxide buildup due to inefficient absorption or scrubbing.

Although this pressure environment will support life for long periods of time, it has certain inherent disadvantages. Even after virtually complete removal of inert gases from the body, there is a finite, though minimal, risk of decompression sickness due to evolved gas. Because oxygen and carbon dioxide are physiologically active gases, they are aborbed rather rapidly from gas-containing cavities in the body. This can result in symptoms, especially in the ears, sinuses and lungs (Hyde, Pines, & Saito, 1963).

The low density of a pure oxygen environment at 109 mm Hg (0.357 gm/liter, 28 percent of air at sea level) attenuates sound transmission and also alters, to some extent, the mechanics of the lung-chest system. The maximum pressure which can be developed by the system is lowered substantially. This inihibits the effectiveness of coughing and may make it difficult to rid the lungs of secretions or foreign matter. Breath holding time is also markedly reduced. On the other hand, the work of breathing at high flow rate is decreased due to reduction in the proportion of turbulent flow at low gas density. Thus, it is easier to sustain hight ventilation volumes during the performance of muscular work (Boothby, 1964). Also, repsiratory water loss may be decreased somewhat at low total pressures (Wortz et al., 1966).

It is not known whether man can tolerate an environment free of "inert" gases indefintiely. The 14-day Gemini flight and a few altitude chamber tests for up to 30 days represent the only available data, and it is noteworthy that these exposures have been at 258 to 282 mm Hg (5 to 5.5 psia), in the main, rather than at the minimum tolerable pressures. When much longer exposures are contemplated, a number of more subtle factors must be considered. These include the possible dependence of man himself, or of his nomal and essestial saprophytic bacteria on trace amounts of nitrogen or other "inert" gases. One study has also indicated tha cell wall fragility may be increased at low total pressures (Bomadini, 1966). Such question as these can only be answered by much longer experiments than those which have been conducted to date.

Man has succesfully tolerated exposures of 56 days to environments containg physiological pressure of oxygen, with helium as the diluent, at a total pressure of 258mm Hg (5.0 psia). Very careful medical, biochemical, physiological, and psychological studies disclosed no adverse effect during this period of exposure other than those which are inevitable under reduced pressure and which have been mentioned (Welch et al., 1966).

In summary, low barometric pressures, in and of themselves, do not appear to be harmful to man, insofar as they have been studied critically. There are disadvantages at pressures so low that pure oxygen must be used as the sole atmospheric constituent; many of these are minimized or alleviated by the addition of a small proportion of a diluent gas. Pressures as low as 5 psia appear to be innocuous for fairly long exposures.

1.3.2: References: Human Tolerance for Low Barometric Pressures

Boothby, W. (Ed) Handbook of respiratory physiology. USAF School of Aviation Medicine, Randolph Air Force Base, Texas, 1954.

Hyde, A.S., Pines, J., & Saito, I. Atelectasis following acceleration: A study of causality Aerospace Medicine, 1966, 37, 449150-157

Welch, B.E., et. al. The study of man during a 56-day exposure to an oxygen-helium atmosphere at 258 mm Hg total pressure: Thirteen reports by various participating investigators. Aerospace Medicine, 1966, 37, 449-462, 552-608.

Wortz, E.C., et al. Reduced barometric pressure and respiratory water loss. USAF SAM TR-66-4, School of Aviation Medicine, Broks Air force Base, Texas, 1966.

1.4: Human Tolerance for Gaseous Environments Composed of Air

1.4.1: Discussion: Human Tolerance for Gaseous Environments Composed of Air

Man has been successfully adapting to a wide range of barometric pressures for many centuries. A skeleton roughly 9000 years old was recently found in Peru at an elevation of 13,800 feet, equivalent to a pressure 450 mm Hg (8.65 psia). Extensive studies have been carried out on acclimatized natives at elevation sof 15000 feet in the Andes and on partially acclimatized mountaineers at 19000 feet and above in the Himalayas. These environments are not optimal, and they exert a considerable physiological toll (see Hypoxia), but they are survivable for substantial periods of time. There is little evidence that long-term inhabitants at elevations above 10,000 feet differ substantially from their sea level counterparts except for decreased work tolerance and the presence of certain body adjustments to the lower partial pressure of oxygen at that altitude.

The usual range of barometric pressure at sea level in the Unite States is from about 29 to 31 inches of mercury (14.25 to 15.25 psia). Chages occur relatively slowly except under very unusual meterological conditions. While certain psychological and physiological disorders have been attributed to such changes in pressure, there is no proof of a causal relationship.

There are mines on earth in which maximum depths exceed 10,000 feet below sea level, equivalent to a barometric pressure of at least 20 psia. There is no evidence that men working at these depths have been harmed by the pressure.

Increasing interest in undersea explorations during recent years has led to a number of long-term human studies at presure substantially higher than those normally encountered by man. While excessive pressures of both nitrogen and oxygen are toxic to man and animals (see Atmoshphere), some of the earlier studies in which air was used as the gaseous medium (Conshelf I, two men, 7 days, 2.05 atm absolute; Conshelf II, six men, 30 days, 1.95 atm absolute; Tekite, four men, 60 days, 2.27 atm absolute) have shown that man can tolerate at least 2 months of exposure to these enviroments without apparent harm (Aquadro & Chouteau, 1967)

1.4.2: References: Human Tolerance for Gaseous Environments Composed of Air

Aquadro, C.F., & Chouteau, J. Problems of extreme duration in open sea saturation exposure. In C.J. Lambertsen (Ed.), Proceedings of the third symposium on underwater physiology. Baltimore: William and Wilkins Co., 1967, pp. 98-108.

1.5: Human Tolerance for High Barometric Pressure

1.5.1: Discussion: Human Tolerance for High Barometric Pressure

Bert, in 1876 (translated by Hitchcock & Hitchcock, 1943) described oxygen toxicity. While this problem is discussed in Atmosphere, it should be noted here that as man has extended his technological capability under the seas, he has found that if oxygen poisoning and nitrogren narcosis can be avoided, his tolerance for high barometric pressures is considerable.

If the partial pressure of oxygen in the lungs is maintained at physiological levels, and it the parical pressure of nitrogen is kept below toxic limits, other inert gases may be added to man's environment in large amounts. The majority of work in this area has used helium as the inert pressurizing gas, though some research has been conducted with other noble gases, notably argon and neon. Hydrogen has not been popular because of its flammability when mixed with oxygen, though it also is physiologically inert and has some theoretical advantages for work at extremely high pressure (see Atmosphere).

Leaving aside problems due to changing presures, the physiological problems encoutntered in a high pressure environment are due almost entirely to the physical characterisitics of the gas mixture used to create that environment.

At rest, man's instantaneous repsiratory flow rate rarely exceeds 1 liter per second. Under these circumstances, most flow in the airway system is laminar; turbulent flow occurs only at branchings and in the smallest terminal bronchial tubes. When physical work is performed, however, ventilation volume and flow rates increase in proportion to the power output. Under these circumstances volumes of 60 to 120 liters per minute and peak flow rates of 5 liters per second are not uncommon. the proportion of turbulent flow increases substantially and with it, the metaboloic work required to move the air.

Otis, Fenn and Rahn (1950) derived equations which describe the work of breathing at various barometric pressures. They showed that the work required to produce laminar flow is linearly related to the instantaneous velocity of air movement and is essentially independent of barometric pressure, whereas the work required for turbulent flow is a function of the second power of velocity and is directly related to density or pressure. (In calculating the work of breathing at altitude, the compressibility of alveolar air must be taken into account [Jaeger & Otis, 1964]; this factor is relatively unimportant at high barometric pressures. The figures "Calculated Reductions in Maximum Ventilatory Capacity with Increasing Depth Breathing Air or He-O2" and "Measured and Computed Data for Decreases in Ventilation with Increasing Depth at Constnat Values of Respiratory Work" illustrate some effects of high pressure on ventilation. Wood, Bryan, and Koch (1969) have recently demonstrated some of the limiting factors in respiratory mechanics at very high pressures. The theoretical limit for steady-state breathing at depth is the point at which the work to move a given quantity of gas requires all the oxygen which can be extracted by the blood from the increment of gas while it is in the lungs.

It is possible, by using combinations of oxygen, nitrogen, and helium, to maintain a gaseous environment whose partial pressure of oxygen and density remain at sea level values up to a total pressure of 5.74 atm absolute (84.4 psia), at which pressure the mixture contain 3.7 percent oxygen and 96.3 percent helium. (See the figure "Mixtures of O2, N2, and He Which Will Maintain Sea Level Equivalent Density and Normal PO2 in the Lungs at Various Total Pressures.") At greater pressures, the density of an appropriate oxygen-helium mixture increases almost in proportion to the total pressure. (See the figure "Density of Mixtures of He and O2 Which Will Maintain a Sea Level Equivalent PO2 in the Lungs.") Using oxygen-helium mixtures, brief habitability studies ahve been

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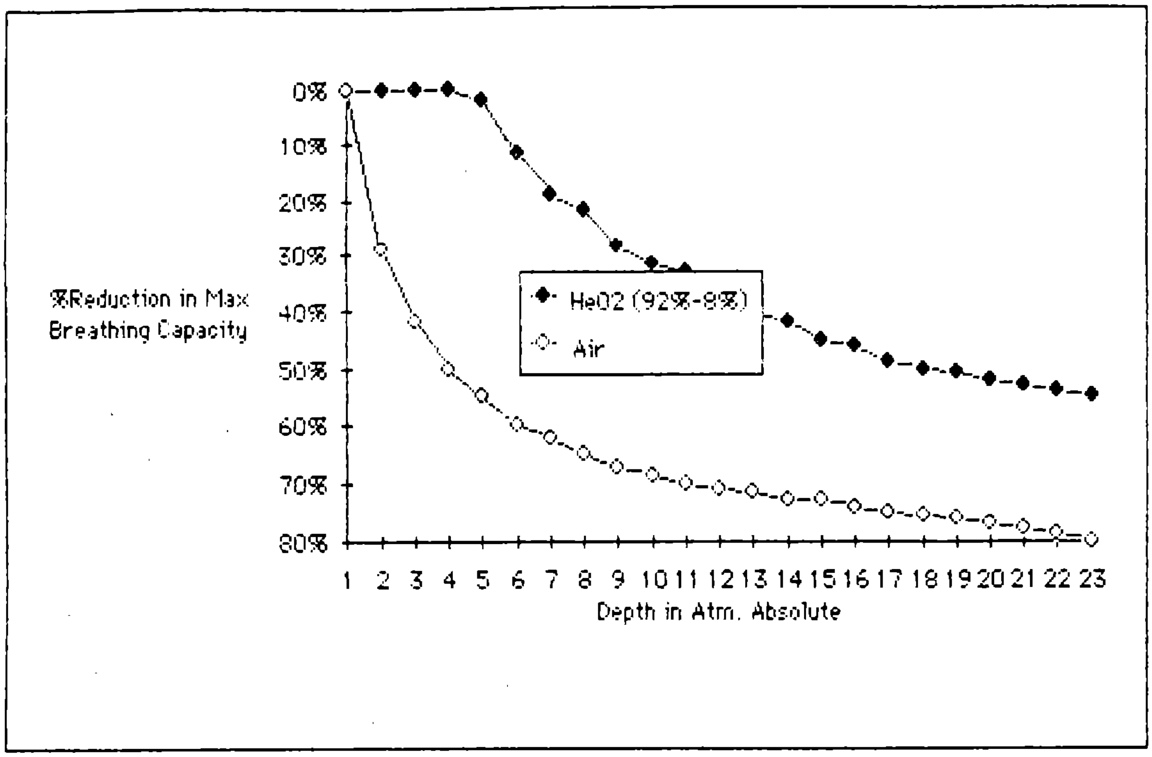
carried out at pressures as great as 684 psia (equivalent to 1500 feet of water) and much longer experiments have been conducted to lesser depths (Aquadro & Chouteau, 1967). These are discussed in more detail in Atmosphere, since it appears that most of the physiological changes observed are due to the gases in the breathing mixtures, rather than to the pressure per se.

Other problems must be considered when man lives in a gaseous environment composed mostly of helium. The thermal conductivity of this gas is high; as a result, higher environmental temperatures are required to maintain man in the zone of thermal neutrality (see Temperature). Very recent studies indicate that during work at depths greater than 600 feet, respiratory heat lossses are considerable and can threaten man's ability to maintain thermal equilibrium even in the face of increased heat production (Rawlins, 1970). Speech is also a problem; the low density of helium produces a rise in the fundamental pitch of the human voice (Cook, 1964; Cooke and Beard, 1965, Wather-Dunn, 1967). While this is partially compensated for over a period of time, intelligibility if appreciably decreased.

Man;s ultimate tolerance limits for high barometric presure are not known. It is possible that the work of breathing at rest will set a practical limit, although there may well be other factors yet-undetected which will limit longer stys at lesser pressures (see Atmosphere). In an effort to extend very considerably the tolerance limits, Kylstra (1967) has conducted experiments in which water instead of air is used as the carrier of oxygen and carbon dioxide. This technique, radical though it seems, may well be feasible at later point in time. Extrmemly hgigh static pressures may curtail or interfere with biochemical reactions which involve changes in tissue or molecular colume (Fenn 1967).

1.5.2: Figure: Calcuated Reductions in Maximum Ventilatory Capacity



Estimated Reduction in Maximum Breathing Capacity with Deep Dive
(air and 8% oxygen in helium)

1.5.2.1: Figure: Keywords

Calculated reductions, maximum ventilatory capacity,
increasing depth, breathing, air, He-02,
breathing capacity, deep dive, oxygen, 02, helium, He, maximum breathing capacity,
barometric pressure,
atmospheres absolute, depth

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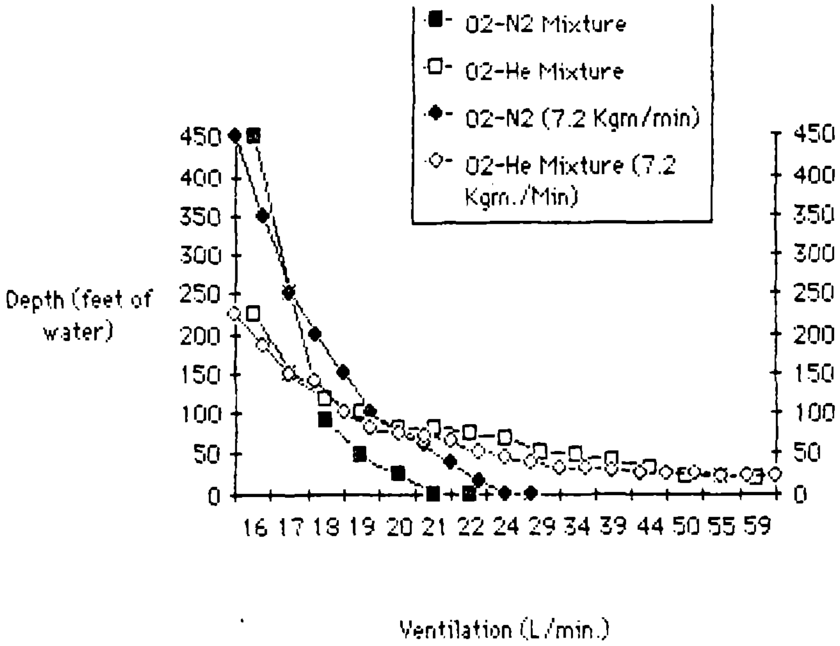
1.5.3: Measured Computed Data for Decreases in Ventilation



1.5.3.1: Figure: Keywords

Decrease in ventilation, 200 ft, increasing depth, constant values, respiratory work, barometric pressure, ventilation, depth, 02-N2 mixture, 02-He mixture

1.5.4: Figure: Mixtures of 02, N2, and He for Sea Level Equivalent Density

1.5.4.1: Figure: Graphic

1.5.4.2: Figure: Keywords

Gaseous mixtures, 02, N2, He, sea level equivalent density,
lungs, concentration of gas, barometric pressure,
breakpoint: 5.74 atm, 156 ft, depth, sea water

1.5.5: Figure: Mixtures of He and 02 for Sea Level Equivalent P02 in Lungs

1.5.5.1: Figure: Graphic

1.5.5.2: Figure: Keywords

Density of mixtures of He and 02, sea level equivalent P02,
lungs, barometric pressure, depth in sea water, concentration of oxygen, 02, pressure, atmospheres absolute

1.5.6: References: Human Tolerance for High Barometric Pressure

Aquadro, C.F., & Chouteau, J. Problems of extreme duration
in open sea saturation exposure. In C.J. Lambertsen

(Ed.), Proceedings of the third symposium on underwater physiology. Baltimore: Williams and Wilkins Co., 1967, pp 98-108.

Bert, P. Barometric Pressure. Columbus, Ohio: College Book Co., (translated by Hitchcock, M.A., & Hitchcock, F.A.), 1943.

Billings, C.A. Pressure. In P. Webb (Ed.), Bioastronautics Data Book. NASA SP-3006, National Aeronautics and Space Administration, Washington, D.C., 1964.

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Cooke, J.P. Sound trnsmission in helium and various gases at low pressure. USAF SAM TDR-64-43, School of Aviation Medicine, Brooks Air Force Base, Texas, 1964.

Cooke, J.P. and Beard, S.E. Verbal communication intelligibility in oxygen-helium and other breathing mixtues at low atmospheric pressures. USAF SAM TR-65-269. School of Aviation Medicine, Brooks Air Force Base, Texas, 1965.

Fenn, W.O. Possible role of hydrostatic pressure in diving. In C.J. Lambersen (Ed.), Proceedings of the third symposium on underwqter physiology. Baltimore: Williams and Wilkins Co., 1967.

Jaeger, M.J. & Otis, A.B. Effects of the compressibility of alveolar gas on the dynamics and work of breathing. USAF SAM TDR-63-71, School of Aviation Medicine, Brooks Air Force Base, Texas, 1964.

Kylstra, J.A. Advantages and limitations of liquid breathing. In C.J. Lambersen (Ed.), Proceedings of the third symposium on underwater physiology. Baltimore: Williams and Wilkins Co., 1967.

Otis, A.B., Fenn, W.O., & Rahn, H. Mechanics of breathing in man. Journal of Applied Physiology, 1950, 2, 592-607.

Wather-Dunn, W. Limitations of speech at high pressures in a helium environment. In C.J. Lambersen (Ed.), Proceedings of the third symposium on underwater physiology. Baltimore: Williams and Wilkins Co., 1967.

Wood, L.H., Bryan, A.C., & Koch, G.H. Limitations of ventilation in a hyperbaric environment. Preprints of Scientific Program, Aerospace Medical Association Meeting, Washington, D.C., May, 1969, P;. 196-197.

Workman, R. O., cited by Wood, W.B. Ventilatory dynamics under hyperbaric states. In C.J. Lambertsen & L.J. Greenbaum, Jr. Proceeding of the the second symposium on underwater physiology Research Council Publication 1181, Washington, D.C.: National Academy of Sciences-National Research Council, 1963, Pp. 109-123.

1.6: Changes in Barométric Pressure

1.6.1: Effects of Increases in Barometric Pressure

1.6.1.1: Problems Due to Trapped Gas within the Body

Increases in barometric pressure are encountered during descents through th atmosphere (whether in space vehicles, aircraft, or elevators), during repsressuization of a space vehicle following extravehicular activity, and during dives in water. Local increases in presure within the body, sometimes of consierable magnitude, occur with coughing, sneezing, blowing the nose, and with mechanical straining in the act of defecation. Exposure to high dynamic pressures, as well as high rates of change of pressure, occur when the body is suddenly subjected to windblast during ejection from aircraft. Still highter pressures are encountered in the vicinty of an explosion.

1.6.1.1.1: The Ear

1.6.1.1.1.1: Discussion: The Ear

The eardrum is a slightly flexible partition between the external ear canal and the middle ear, a small air filled cavity which communicates with the environment only through the Eustachian tube, which opens into the back of the nose (see the table: "Effect of Pressure Change on Middle Ear"). Air leaves the middle ear passsively during decompression or ascent, but the mucous membrane lining the tube tends to prevent air from reentering the Eustachian tube without voluntary muscular effort during recompression.

Rapid recompressions from 28,000 feet to sea level, an increase of 10 psia, were performed by Raeke and Freedman (1961). The rates of change are shown in the figure "Rapid Compressions from 4.7 to 14.7 Psi". None of the subjects sustained serious ear damage during the tests. in three of 28 tests, however, it was necessry to initiate reascent of the chamber to aid the subjects in equalizing the pressure across the eardrum.

The table "Types of Ear Compaints Encoutered During Change in Baromentric Pressure" summarizes the symptoms which result from a differential pressure across the eardrum. Once high differentials exist, it is difficult or impossible to force air into the middle ear voluntarily; avoidance of such differentials requires frequent attention during rapid descents. Descents of less than 500 feed per minute in the lower atmosphere (0.25 psia/minute) are usually tolerated by inexperienced air passengers without difficulty, though modern pressurization contollers are usually operated at perhaps half this rate. The likelihood of difficulty in "clearing the ears," and thus the likelihood of barotitis, as ear trouble due to pressure change is called, is much greater in an individual in whom the nasal mucous membranes are swollen, with resultant constriction of the Eustachian tube orifice. This occurs with upper respiratory infections such as the common cold, nasal allergies (hay fever), and the like. Barotitis if the most common medical problem in the flying popularion, largely because the conditions which cause it are so common in temperate climates.

1.6.1.1.1.2: Figure: Effects of Pressure Change on Middle Ear

1.6.1.1.1.2.1: Figure: Graphic

1.6.1.1.1.2.2: Figure: Keywords

Effect of pressure change on middle ear,
External ear canal, ear drum, Eustachian tube,
ascent, descent

1.6.1.1.1.3: Figure: Rapid Recompressions from 4.7 to 14.7 psi

1.6.1.1.1.3.1: Figure: Graphic

1.6.1.1.1.3.2: Figure: Keywords

Rapid compression, barometric pressure,
equivalent altitude, recompression

1.6.1.1.1.4: Table: Types of Ear Complaints Encountered

Types of Ear Complaints Encountered During
Change in Barometric Pressure

Ascent (mm Hg)	Complaint	Descent (mm Hg)
0	No sensation; hearing is normal (level flight)	0
+ 3- 5	Feeling of fullness in ears.	-3 - 5

+10-15	More fullness, lessened sound intensity	-10-15	
+15-30	Fullness, discomfort, tinnitus in ears; "pop" as air leaves middle ear Desire to clear ears; if this is done, symptoms stop	-15-30	Ears usally
+30 plus	Increasing pain, tinnitus, and dizziness	-30-60	
	Severe and radiating pain, dizziness, and nausea	-60-80	
	Voluntary clearing becomes difficult or impossible	-100	
	Eardrum ruptures	200+	

(Modified from Adler, 1964)

NOTE: During ascent pressure in middle ear is higher than the ambient pressure; during descent, middle ear pressure is lower than ambient .

1.6.1.1.1.5: References: Increases in Barometric Pressure: Trapped Gases: The Ear

Adler, H.F. Dysbarism. USAF SAM Review 1-64, School of Aviation Medicine, Brooks Air Force Base, Texas, 1964.

Raeke, J.W., & Freedman, T. Human response to rapid recompression. Presented to Aerospace Medical Association Meeting, Chicago, 1961.

1.6.1.1.2: The Sinuses

The paranasal sinuses are small, rigid air filled cavities in the skull. They communicate with the nose through small ducts. Unlike the Eustachian tube, these ducts show no particular predispostions to blockage during descent. Inflammation or swelling of the mucous membranes of the sinuses or nose, however, can cause partial or complete obstruction of these ducts, and thus a differential prssure between the sinus and the environment during chages of environmental pressure Severe or incapacitating pain may result, a condition known as barosinusitis.

1.6.1.1.3: The Teeth

1.6.1.1.3.1: Discussion: the Teeth

Occasionally, toothaches are reported during changes in barometric pressure; this is called barodontalgia. The condition usually occurs in teeth which have been filled, or in which cavities are present. The explantion usually given is that a small air bubble is trapped below a restoration or in the decayed tooth substance. There is, however, evidence that loose fillings may allow saliva to penetrate into the interior of these teeth during changes in pressure.

1.6.1.1.3.2: References: Increases in Barometric Pressure: Trapped Gases: The Sinuses

Adler, H.F. Dysbarism. USAF SAM Review 1-64, School of Aviation Medicine, Brooks Air Force Base, Texas, 1964.

1.6.1.1.4: Summary - Ear, Sinuses, Teeth

1.6.1.1.4.1: Discussion: Ear, Sinuses, and Teeth

Symptoms due to trapped gas are relatively common in altitude chamber flights where the changes in pressure are fairly large. It should be noted, however, that the rate of pressure change with changes in altitude is greatest near sea level. The threee problems cited, therefore, commonly occur at comparatively low altitudes and in diving. Barotitis, in particular, often occurs below 5000 feet altitude. The incidence of such problems in a large number of routine altitude indoctination flights is shown in the table "Incidence of Symptoms Due to Trapped Gas".

1.6.1.1.4.2: Table: Incidence of Symptoms Due to Trapped Gas

INCIDENCE OF SYMPTOMS DUE TO TRAPPED GAS

SYMPTOMS	SEVERITY (GRADE)				TOTAL
	I	II	III	IV	
Ear Pain	6650	2437	514	-	9601
Abdominal pain	2738	1187	322	12	4259
Sinus pain	1516	723	176	-	2415
Toothache	285	142	118	-	545
TOTAL	11 189	4489	1130	12	16 820

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*Numbers shown are rates per 100 000 man-flights
(From data or Berry, 1958)

1.6.1.1.4.3: References

Berry, C.A. Severe disbarism in Air Force operations and training. U.S. Armed Forces Medical Journal, 1958, 9, 936.

1.6.1.1.5: The Lungs

1.6.1.1.5.1: Discussion: the Lungs

Unlike the middle ear, sinuses, and teeth, the lung-chest system is capable of wide variations in volume. Its minimum, or residual, volume in an adult male is commonly less the 1.5 liters. When barometric pressure increases, therefore, the volume of gas in the lungs is free to contract. If the lungs are in communication with the environment, air flows into them. During breath-holding diving, however, the volume of air in the lungs contracts in accordance with Boyle's law (allowing for the constant pressure of water vapor).

If the pressure ratio (ratio of final to initial pressure) is such as to compress the air in the lungs to less than the residual volume of the system, a phenomenon known commonly as "squeeze" occurs. The relative vacuum in the lungs causes an increase in the blood volume in the chest. The lungs are pulled toward a position of greater collapse than they can attain within the closed chest; the result is pain and hemorrhage into the lung tissue and ariways. This condition if os practical importance only in underwater work, where large changes in pressure can occur rapidly. If is the limiting factor in breath-holding diving (Schaefer et al., 1968). Squeeze can also occur in face masks used in diving if air in not introduced into the mask during descent.

1.6.1.1.5.2: References: Increase in Barometric Pressure: Trapped Gas: The Lungs

Shaefer, K.E., et al. Pulmonary and circulatory adjustments determining the limits of depth in breathhold diving. Science, 1968, 162, 1020-1023.

1.6.1.2: Problems Due to High Dynamic Pressure within the Body

1.6.1.2.1: High Dynamic Pressure: Text

During ejection or manual escape from aircraft, a pilot is suddenly thrust from a cockpit in which the air around him is moving at the same velocity he is into an environment in which he is a projectile. The dynamic pressure Q exerted on the frontal surface of his body (if he is facing forward) is a function of the air density and his airspeed. (See next frame for equation)

Pressures of 1000 (7 psig) are not uncommon during high speed, low altitude ejections. The figure "Data obtained on two subjects in ejection seat.." shows data collected during human exposures to high dynamic pressure produced on an underwater centrifuge. The figure shows injuries produced by the more severe exposures. The Figure "Leg and elbow speration forces.." shows the separation forces developed on the arms and legs plotted against overall dynamic pressures (Fryer, 1962). It should be noted that ejection in the rearward facing position offers a substantial degree of protection against Q forces, by interposing the seat between the subject and source of pressure (see Sustained Linear Acceleration).

1.6.1.2.2: High Dynamic Pressure: Equation

$$Q = \frac{P v^2}{2}$$

1.6.1.2.3: Data Obtained on Two Subjects in Ejection Seat

1.6.1.2.4: Leg and Elbow Separation Forces

1.6.1.2.5: High Dynamic Pressure: References

Fryer, D.I. Physiologic effects of exposure to ram pressure. Aeorspace Medicine, 1962, 33, 34-41.

1.6.1.3: Problems Due to Blast

1.6.2: Effects of Decreases in Barometric Pressure

2: Atmosphere

3: Termperature

4: Sustained Linear Acceleration

5: Rotary Accerleration

6: Impact

7: Vibration

8: Weightlessness

9: Ionizing Radiation

10: Toxicology

11: Respiratory System

12: The Vestibular System

13: Vision

14: Auditory System

15: Noise and Blast

16: Human Control Capabilities

17: Atmosphere Control

18: Work, Heat and Oxygen Cost

19: Combined Environmental Stress

20: Aerospace Vehicle Management