When Being Is Not

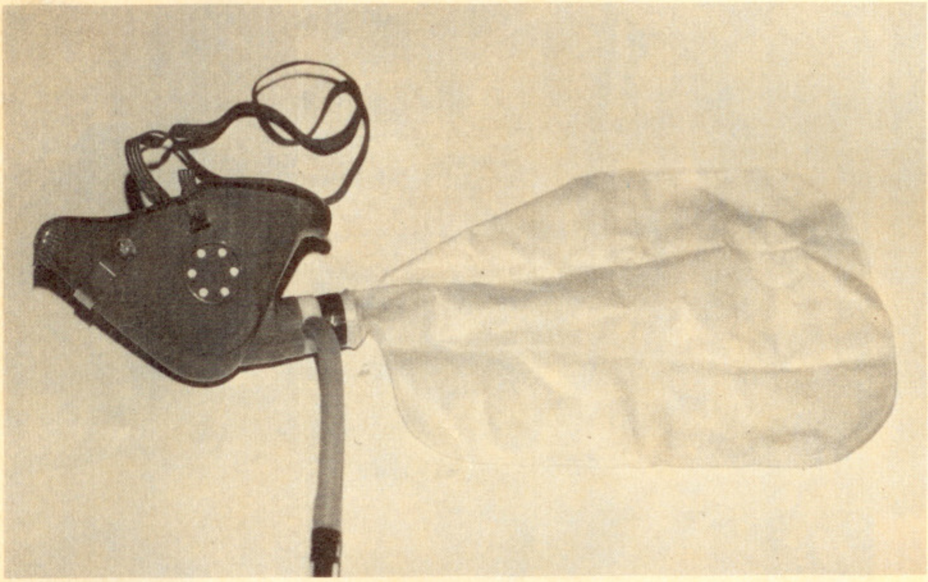

Figure 1. *Hudson-type mask is supplied primarily for routine hospital use, but is widely used in general aviation oxygen systems.*

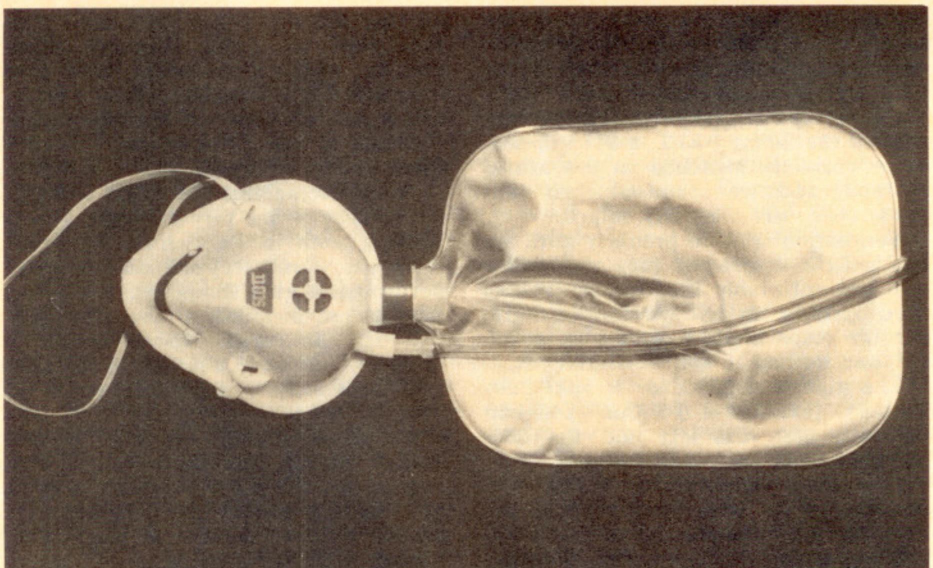

Figure 2. *Scott Sky Mask, another commercially popular mask in general aviation use, is supplied by Scott Aviation Co.*

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■■ If you're like most pilots, your knowledge of altitude life-support systems is limited to the concept: "As long as I'm 'on oxygen' over 10,000 feet, everything is okay." Since no one seems to have said much to the contrary, it seems a reasonable assumption.

I want to tell you about the times when your oxygen system may not be good enough.

When I finished my two-year duty as a flight surgeon in the USAF, I moved to Utah and bought into a Piper Comanche 250. The local terrain being what it is, I began to shop around at our local FBO's for an oxygen system.

Although the protection range of any oxygen system is limited to certain altitudes, I found that appallingly little information is available concerning the efficiency of the constant-flow oxygen systems used in general aviation. (The USAF stopped using constant-flow equipment before World War II. If you think the USAF has studied the general aviation problem, you don't realize how much more sophisticated their equipment is.) Since in my medical career I've published a number of research papers on methods of oxygen measurement, I figured that if anyone was going to look into the efficiency of oxygen equipment for light aircraft, it would probably have to be me.

To summarize the problem, I should mention that oxygen comprises 21% of the atmosphere at all altitudes. As the total atmospheric pressure decreases with altitude, the available oxygen pressure decreases in proportion.

Symptoms of hypoxia may begin as low as 5,000 feet with decreased night vision. At 10,000 feet, forced concentration, fatigue, and headache may occur. At 14,000 feet, forgetfulness, incompetence, and indifference make flying without supplemental oxygen quite hazardous, and at 17,000 feet, serious handicap and collapse may occur. In

'On Oxygen' Good Enough

the regular smoker, these effects all occur 3,000 to 4,000 feet lower.

There are no reliable guides to the effects of hypoxia except the altimeter. A pilot impaired by hypoxia is unable to judge his degree of impairment.

At 34,000 feet, breathing 100% oxygen is equivalent to breathing air at sea level. At 40,000 feet, breathing 100% oxygen is equivalent to breathing air at 10,000 feet. The goal of supplemental oxygen systems is to supply a sea-level equivalent to provide some margin for safety. Therefore, 34,000 feet remains the absolute limit for this type of equipment.

The fact is, however, that although your *tank* may have 100% oxygen, general aviation's constant-flow *masks* deliver a far lower percentage than 100%, because of leaks in the masks and dilution with outside air. In its "Flight Surgeon's Guide," the USAF states that "an arbitrary altitude ceiling of 25,000 feet has been established for this type of equipment"—no matter how sophisticated. This is also the current FAA recommendation.

You should understand the numbers 34,000 feet and 40,000 feet and be ready to disbelieve any statement that includes them. They are often quoted in a pseudo-scientific way by manufacturers who don't know the difference between the percentage of oxygen in the tank and the percentage actually received by the person using the system.

The heart of the problem, as already noted, is in the mask. You probably have the type shown in Figure 1, which is in widespread use and is supplied by a number of manufacturers of oxygen systems for aviation. This mask is also supplied for routine hospital use by the Hudson Oxygen Therapy Sales Co., where it originated. I call it the "Hudson mask," since Charles Hudson holds the patent.

Two other commercially popular oxygen masks for general aviation are the Scott Sky Mask (Figure 2) and the Scott Duo-Seal Mask (Figure 3), manufactured by Scott Aviation Co.

These three types of constant-flow masks were the ones I selected for my study.

To analyze the efficiency of an oxygen system, you need only measure the amount of oxygen present in the arterial blood at the various altitudes. But, even easier, a measurement of the oxygen present in the lungs or in the expired breadth at ground level can be used to predict the blood levels at any altitude. I decided to use both measures.

There was no difficulty in finding subjects willing to undertake an aerial tour of the Salt Lake Valley, even with an arterial catheter in their arms. Because of uncertainties of weather and the difficult schedules of the physicians and nurses who served as subjects, we waited until we got to the airport to insert the arterial needles. We used the right wing of the Comanche as an operating table of sorts.

Subjects lay supine on the wing, left arm extended and exposed, while one of the physicians did the honors with the needle. We spilled a little blood on the wing. All sorts of medications and supplies were apparent. One physician-subject felt slightly nauseated after being stuck and lay doubled on the ground for a few minutes to recompose himself. Despite all this, several strangers drove or taxied by and hurried away without wanting to get involved. I was glad the airport cops didn't see us.

We filed IFR local and flew the Comanche in holding patterns between Salt Lake City and Provo, at progressively higher altitudes, drawing arterial blood samples while our subjects breathed ambient air and while they breathed oxygen with the various masks. We put the samples on ice so that we could analyze the oxygen content of the blood with standard hospital equipment when we were back on the ground.

(We drew blood samples from subjects breathing ambient air in order to reproduce known altitude information and thereby validate our other results. For safety, one physician-pilot was on oxygen at all times during our flights.)

Each flight proved to be an adventure in aerospace medicine and dramatized the hostile environment of high altitude. One study was suspended by a distressing episode at 18,000 feet: collapse and unconsciouness of a nurse-subject, who simply slumped over in the seat with a euphoric smile still on her face. True scientists, we got our blood sample, slapped the oxygen back on, and quickly descended. She revived immediately.

Later, our nurse-subject reported that her only sensation was sleepiness. She had the feeling that she was going out, but didn't care. As she was coming around, our voices and the pressure of the mask against her face were irritating, and she wished we would leave her alone. Although she was awake for the approach and landing, she had no memory of them.

During the same flight, on which I was also a subject, I was flying the airplane in ways that were very amusing to my physician-pilot colleague. At the lower altitudes, I tracked the holding pattern quite exactly. At 15,000 feet and above, the CDI was pegged in one direction or the other whenever I was off oxygen, only to return to normal when I was on oxygen.

On another flight when I was not a subject, and when I stayed on oxygen the entire time, I worried about our diminishing oxygen supply at 18,000 feet. I became short of breath and felt slightly dizzy, and my fingers began to tingle. Hyperventilation!

Irritated with myself, I started an immediate descent. We never exceeded a 1,000-fpm descent, but at 8,000 feet, one of the subjects experienced a severe stabbing pain in the face. Although he had been able to clear his *ears* before the flight, it didn't prevent him from developing barosinusitis—a sinus block. My flight bag includes Neo-Synephrine nasal spray for just such an occasion. With treatment, the pain disappeared

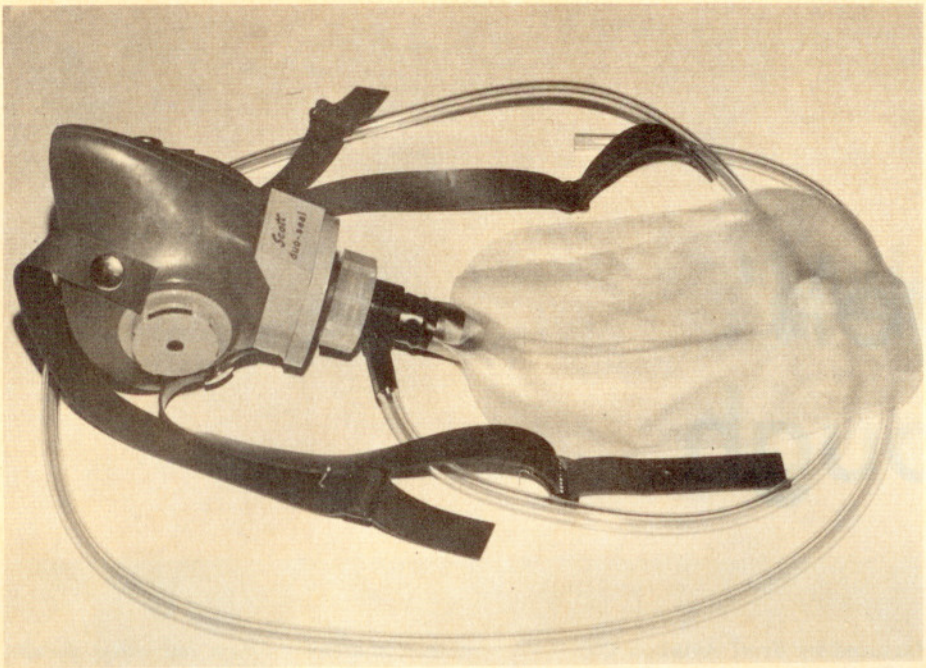

Figure 3. Scott's Duo-Seal Mask has a built-in microphone, making it unnecessary for the pilot to remove the mask for radio communication.

rapidly, and we concluded with a beautiful night approach into Salt Lake International.

When we delayed at the hangar, an airport cop drove up to see what we were doing. Fortunately, the syringes were out of sight, and darkness hid the blood that we had spilled on each other. Medical research has its difficult moments.

In the ground tests, we measured inspired and expired oxygen in subjects breathing oxygen with the various masks. For the measurements we used a Perkin-Elmer MGA-1100 mass spectrometer, capable of an instantaneous, continuous analysis.

After we had analyzed more than 50 individual arterial blood samples and literally thousands of individual breaths, we found that the data showed some consistent patterns. In subjects breathing ambient air at 18,000 feet, the hospital computer interpreted our samples as indicating "severe hypoxia" with a "moderate acid-base disorder of acute respiratory alkalosis." And the computer was programmed for hospitalized patients!

Altitude tests indicated that the Hudson-type mask provided only 33% to 40% oxygen in the inspired air, an amount sufficient for a pilot to have a sea-level oxygen equivalent up to about 20,000 feet and a 10,000-foot equivalent up to about 26,000 feet.

The Hudson mask makes relatively poor use of its reservoir bag, which was often seen to collapse into total uselessness as exhaled moisture caused the sides of the bag to stick together. This type of equipment failure results in a sea-level oxygen equivalent up to 10,000 feet and a 10,000-foot equivalent up to almost 20,000 feet.

The Scott Sky Mask provided 51% oxygen at the higher altitudes, with sea-level oxygen protection calculated to 24,000 feet, and a 10,000-foot equivalent up to 28,000 feet.

The Scott Duo-Seal Mask provided 52% oxygen at the higher altitudes, with sea-level oxygen protection up to 25,000 feet and a 10,000-foot equivalent up to 29,000 feet.

All the tests were done with the same oxygen tank and regulator, the Rajay SK-10, which delivers a constant flow of oxygen of 2.2 liters per minute at sea level and 4.0 liters per minute at 20,000 feet, with straight-line variation between those points. Different tank and regulator combinations might provide slightly different results; however, this system is typical of most, and the differences would be small.

From an operational perspective, single-engine turbocharged aircraft, which commonly have a service ceiling over 30,000 feet, are capable of exceeding the protection limits of properly used oxygen equipment of all types. There are clearly some situations where "being on oxygen" is not good enough.

Insisting on a sea-level oxygen equivalent may seem unnecessarily conservative at first glance, but there are subtle pitfalls that are apt to markedly degrade the efficiency of the oxygen system.

- If the reservoir function of the bag becomes inoperative, there is a sudden loss of 10,000 feet of protection without warning.
- If the mask shifts to provide a less adequate fit, efficiency will decrease.
- If there is no microphone built into the mask, the pilot must remove his mask for radio communication as well as for normal conversations with passengers.
- In the 18,000-foot altitude range, individuals can develop severe hypoxia in less than a minute with the mask off, and this can easily happen to a pilot whose attention is distracted by a complicated clearance or a distorted radio transmission.

Several of these events are apt to occur together; therefore, maintaining a sea-level equivalent makes good sense.

Hyperventilation is a condition of shortness of breath and excessively rapid, deep breathing usually associated with anxiety. Its symptoms were mentioned earlier in the description of my own episode of hyperventilation, when I learned that not even a flight surgeon is immune.

Unfortunately, hyperventilation tends to degrade the efficiency of oxygen delivery by all of these masks; consequently, a pilot hyperventilating at high altitude is likely to become hypoxic at the same time, and that's not a nice combination. It would be possible to design a mask that would protect against hyperventilation, but so far no one has. In the meantime, we are left with the recommendation to "breathe slower" or to breathe into a paper bag. If you don't have a copilot, you'd be wise to descend, if possible, to lower altitudes until the hyperventilation is controlled.

What do the "Big Three" general aviation manufacturers do about oxygen masks? Beech uses Scott Aviation Co. products in its Baron and Bonanza lines, with the Sky Mask in the passenger seats and the Duo-Seal Mask, with a built-in microphone, in the pilot seats. Piper uses Scott products exclusively, and Cessna uses some Scott equipment and some from other vendors.

Based on my studies, I make the following recommendations for oxygen use:

- If you are flying a nonturbocharged aircraft under 20,000 feet, being "on oxygen over 10,000 feet" is probably good enough—as long as your tank has sufficient endurance, of course.
- Above 20,000 feet, a sophisticated type of mask like the Scott Duo-Seal, with a built-in microphone, should be considered essential for the pilot. The Beech practice makes a lot of sense.
- The USAF guideline of a 25,000-foot altitude ceiling should be followed with constant-flow oxygen equipment of any type. You might go to 29,000 feet with the Duo-Seal type mask, but with a very narrow margin of safety. And if you go, don't tell them I sent you.
- The Hudson-type mask was not designed for aviation and should be left in the hospital where it belongs.

In short, we should all maintain a deep respect for the hazards of altitude, and we should recognize the situations in which being "on oxygen" is not good enough. □