Curriculum Units by Fellows of the Yale-New Haven Teachers Institute
1988 Volume VI: An Introduction to Aerodynamics

Daedalus: The Long Odyssey from Myth to Reality

Curriculum Unit 88.06.10
by Anthony B. Wight

Table of Contents:

(figure available in print form)

Figure 1. Woodcut by the German painter and engraver, Albrecht Durer depicts Daedalus and Icarus fleeing the island of Crete.

Unit Overview

> “ . . . they shall mount up with wings like eagles . . . ’’

—The Prophet Isaiah, circa 700 B.C. According to Greek mythology, a man named Daedalus, imprisoned on the island of Crete, crafted for himself out of feathers and wax a pair of wings. Fastening the wings to his arms, he jumped from a cliff and soared to freedom on the Greek mainland. The event remains mythological, though cultural historians trace origins of the story to about 3500 B.C. On April 23, 1966, in a record-shattering display of human physical prowess and modern flight technology, a Greek cyclist emulating the myth flew under his own power in the superlight aircraft “Daedalus II’’, constructed by a team of scientists and students at MIT, from the island of Crete to the island of Santorini, 74 miles across the Aegean Sea. The long flight from myth to reality was at least completed!

This unit is intended for use in general science, physical science, and modern technology courses in grade 7-12. The most ideal setting for the unit would be an interdisciplinary study of the relationship between science and technology, on the one hand and the interaction between technology and culture, on the other. However, individual teachers closely attuned to the interests and skill levels of their students can adapt the material presented to enrich a wide variety of courses and curricular emphases.

Students complain that the study of science is dull, dry and boring. That this is too often true reveals our dependence as teachers upon teaching “about’’ science rather than engaging students in scientific inquiry and process. The scientific method, so easily mistaken as a rigid sequence of steps, deserves to be treated in a much livelier manner as a systematic *pursuit* of knowledge involving *recognition* of a problem, collection of data through *observation* and *experimentation* , and the *formulation* and *testing* of hypotheses. I borrow the underlined terms from Webster’s Ninth Collegiate Dictionary definition of scientific method, but give them emphasis because I believe none of these identified steps can take place without the creative exercise of imagination.

I propose to engage student interest in the study of human-powered flight by leading off with poetic imagery and Greek mythology; in particular, the myth of Daedalus. Initial discussions should examine the myth for its human meanings—the turbulent passions, crimes and punishments, political alliances, deceits, trickery, hope and hubris. Equally attractive is the use of the myth as springboard for discussion of the necessary technology of human flight. Daedalus fashioned simple wings from whatever materials he had on hand—wax, feathers, thread. He and his son would use their arms to generate needed power by flapping the wings. How possible is such flight by humans? What resistances must be overcome? What natural forces might be married to the task? How much energy would be needed? Can a body generate such power?

Teachers using this unit are urged to refer to my seminar colleagues’ units in this volume for more suggestions about teaching the science of flight. In addition, I highly recommend two previously published volumes of YNHTI Curriculum Units for further suggestions on mythology: 1983, Volume II: *Greek and Roman Mythology* and 1984, Volume II: *Greek Civilization* .

II. *Learning Goals*

Upon completion of this unit, students will:

1. Know the Daedalus myth and its significance for human aviation.
2. Be able to locate Greece, the island of Crete, and the Aegean Sea on a world map.
3. Compare and contrast mythology, legends and history.
4. Be able to discuss the relationship of imagination to science.
5. Know the major steps in the evolution of human-powered flying (kites, balloons, dirigibles, aircraft)
6. Appreciate the aircraft design contributions of da Vinci, Cayley, the Wrights.
7. Know the four forces affecting flight (lift, gravity, thrust, drag) and how they are related.
8. Understand how to represent forces with vectors
9. Understand and be able to illustrate the difference between lighter-than-air and heavier-than-air flight.
10. Be able to compare the characteristics of hydrogen and helium and explain the importance of the discovery of helium to lighter-than-air-craft.
13. Know the relationships among work, energy and power.
14. Calculate personal power output ratings.
15. Research, prepare and present a class report on one aspect of the history or physics of flight.
16. Know the significance of the “Daedalus II’’ flight for history, science and technology.

III. Suggested Teaching Strategies

1. Reading aloud from the rich literature of mythology and poetry.
2. Student research, writing and retelling of ancient stories, favorite legends, and key events in the history of flight.
3. Lecture, slide and video presentation of historical material.
4. Compiling of a classroom chart/timeline detailing the chronology of flight.
5. Laboratory and field experiments demonstrating density of gases, fluid flow, hot air balloons, laws of motion
6. Calculations of potential energy, kinetic energy, work, and power.
7. Determination of individual power output via bicycle riding and generation of electricity with a bicycle generator.
8. Class mini-technology/culture fair with students preparation of projects and reports tied to the theme “Daedalus:from myth to reality.’’
9. Assign daily “flight checks’’—short writing assignments which will give students opportunities to practice communication skills as well as demonstrate mastery of lesson objectives.

IV. Imagination of flight

“I am eagle, i am eagle!”

—Gherman Titov, Russia’s second astronaut If imagination is truly one of the distinguishing features of the human mind, then *Homo sapiens* had doubtlessly wondered about the experience of flight for thousands of years before the heroic Greeks. Ancient legends, songs and poetry from many cultures reveal the connection of human spirit and transcendent hope with the soaring flight of birds, doves, eagles. Spirits, angels, characters of mythology are depicted in story and graphic arts with diaphanous wings and powers of transport far exceeding that of mere mortals. Since imagination is a most human and humanizing exercise, then “flights of imagination’’ or imaginings of flight provide approaches for interdisciplinary study of aerodynamics and human possibilities.

Who was the first man to fly? According to Greek mythology, it was the skilled Athenian craftsman and inventor Daedalus. Daedalus took as an apprentice his nephew Perdix; however, Perdix proved to be such a talented artisan that Daedalus killed him in a jealous rage. After this crime, daedalus fled to the island of Crete (a 'flight of necessity''?) where King Minos hired him to work on his fabulous palace at Knossos. His work included many ingenious inventions for Minos, including the world's first indoor flush toilet and the *labyrinth* , a maze-like building which held Minos' monstrous mutant child, the Minotaur.

Daedalus later helped Minos' daughter Ariadne elope with Theseus, the slayer of the Minotaur. As punishment for his crime, Minos imprisoned Daedalus and his son Icarus in the labyrinth. To escape, Daedalus made two pairs of wings from feathers, was wax thread. Father and son used the wings to fly from Crete. However, Icarus, in his enthusiasm, flew too high in the sky causing the wax in his wings to melt and he plunged to his death in the sea. Daedalus flew on in grief and reached the mainland. Minos supposedly pursued Daedalus to Sicily where, according to one story, Daedalus killed the king by scalding him in a specially constructed bathtub. Theseus and Ariadne made their way safely to Athens where they became the ruling royalty.

The Daedalus myth has been interpreted for thousand of years in literature and the arts (e.g., Figure 1, woodcut by Albrecht Durer); yet, it remains quite lively and open for student reading and reflection. Daedalus is a mythic hero of human dimensions whose own crimes and shortcomings never go unpunished. From the pre-scientific world of ancient Greece we are given a piercing glimpse of the inner core of our humanity: hubris. Suffering is never far from, and perhaps closely entwined with the greatest accomplishment and achievement. On the other hand, it may inspire students to examine the myth as symbolic of the birth of a new age (Athens/Theseus) through the deposing of an old, obsolete, more barbaric order (Crete/Minos). "The very scientist who, in the service of the sinful king, was the brain behind the horror of the labyrinth, quite as readily can serve the purposes of freedom.'' (Campbell, p. 24) Daedalus, artist-scientist, single-heartedly dedicated to his craft stands in the pre-dawn of the age of flight as the exemplar of the possibility of harnessing of human imagination and technology. (A classroom activity to further explore the myth is suggested with this unit.)

Daedalus, mythological progenitor of flight, is significant as heroic symbol of human imagination and innovation, but not as the reality we seek. Here it will be helpful to point out to students the differences between myth, legend and history. Legend, Webster inform us, is "a story coming down from the past, especially one regarded as historical although not verifiable.'' Myth, on the other hand, is "a traditional story that serves to unfold part of the worldview of a people or explain a belief, practice or phenomenon.'' (Webster's Ninth Collegiate Dictionary) The power of myth lies in its eternal symbolic truth; the greatness of legend lies in its particularity and possibility—it *may* be "historically true.''

Legends of flight are many and may be of interest to students:

—A legend from ancient Persia tells of King Kai-Kaus who flew on a throne carried aloft by captive eagles. (Highland, p.6)
—Bladud, the ninth king of Britain, was killed when he attempted to fly from the Temple of Apollo in Trinavantum (London) using wings covered with feathers. About 850 B.C. (Taylor & Mondey, p.7)
—Mo To Tzu in China about 400 B.C. is said to have invented the kite, constructing one of light

wood. (Taylor & Mondey, p.7)
—At the time of Nero, Simon the Magician is said to have flown over Rome in a fiery chariot which he built. (Robinson, p.52)
—Cyrano de Bergerac, the French poet, wrote of ascending to the Moon by surrounding his body with bottles of dew which lifted him up when rays of the sun caused the dew to rise. (Zisfein, p.10)

V. History of Human Flight

> "At first we will only skim the surface of the earth like young star lings, but soon, emboldened by practice and experience, we will spring into the air with the impetuousness of the eagle, diverting ourselves by watching the childish behavior of the little men or awling miserably around on the earth below us.''

—Jean-Jacques Rousseau, c. 1750 (Canby, p.9)

Rousseau, romantic philosopher and writer in the 18th century, had no idea *how* man was going to fly, except that he was going to fly like birds of nature. However, for centuries before his statement above, humans had been "flying''—at least leaving the bounds of earth for measurable periods of time—by one means or another.

Humans first left the earth not on feathered wings, nor even in balloons, but on giant kites. As mentioned above, the invention of kites is attributed to 4th century B.C. China. Long before they were known in the west, kites were used to lift observers high above the sea for navigation and signaling purposes in shipping and military maneuvers—practices witnessed and reported by the explorer Marco Polo from his travels to the Orient in the 14th century A.D. Kites were used in China not only for observation, but even for the dropping of bombs in battle and for the first known parachute jumps. (Taylor & Mondey, p.8) Granted that kites are tethered and such flight is not "free''; nevertheless, as will be illustrated below, the forces on a kite are similar to those on a bird's wing or airfoil. (Kite making and kite flying are particularly enjoyable ways to study aerodynamics and might easily be joined to any class picnic, field trip, etc.)

Other than kiting, it is fair to say that man's first conquest of the air was in balloons. The roots of balloon science really lie in the discoveries made by Greek mathematician and inventor Archimedes who, in about 200 B.C., explained how and why objects float or sink in liquids. The "lift'' of a floating object depends upon its mass and the mass of the liquid which its volume would displace (i.e., relative densities). For students unfamiliar with Archimedes Principle, mass, volume, and density, some simple laboratory lessons at this point will help them grasp the fundamentals which can then be applied to ballooning. (See any standard General Science or Physical Science text)

The first man to approach flying on a “scientific’’ basis was the English monk Roger Bacon in the 13th century. Studying the work of Archimedes, Bacon envisioned the air about us as a sea of some solid basis. He believed that a balloon could be filled with some lighter substance which he called “ethereal air’’. (Highland, p.6) Four hundred years later, on Italian priest, Francesco de Lana, applied Bacon’s principle of air flight to the design of a boat, complete with mast and sail, which was to be held aloft by four hollow spheres. Each sphere was to be made of very thin copper, 20 feet in diameter. All air was to be removed from the spheres so they would float up in the sky. While impossible to construct, de Lana’s design was an important step in conception.

In Avignon, France (modern new Haven’s sister city!) during November, 1782, Joseph Montgolfier, a paper manufacturer with an inquisitive and inventive mind, observed the upward rush of smoke and hot air from a fire. Constructing a simple cloth bag, he filled it with hot air and watched it rise to the ceiling. The European age of lighter-than-air flight had begun! (see Canby, p.9) Joseph and his brother Etienne had heard about the discovery of a gas lighter than air by the English chemist, Henry Cavendish. Cavendish called his gas “inflammable air’’; it was later renamed hydrogen. (Scarry, p.47) The Mongolfiers at first assumed that a similar light gas was produced by flame; however, they soon realized that the heating of air itself was sufficient to float a balloon and within a year ascents were quite frequent in France by both hot air and hydrogen balloons.

Unknown to the Montgolfiers and to most of the European world, the first demonstration of hot air ballooning is now known to have taken place in 1709—74 years before the Avignon discovery! A brilliant young Jesuit priest, Father Laurenco de Gusmao of Brazil built and displayed before the King of Portugal working models of paper balloons rising above a small basket of flame. The Montgolfiers still have the distinction of being the first to send a person aloft in a balloon; but Gusmao was first to show the principle—even if he did cause a minor fire in the palace chamber during the demonstration! (Taylor & Munson, pp. 19 & 506)

The next 150 years were filled with filled with scientific advances aided by balloons and their more controllable “offspring’’, dirigibles. Though hot-air ballooning gained and still retains great popularity, hydrogen-filled balloons became the favorite for scientific research in the atmosphere and for large dirigible use. Helium, nearly as buoyant as hydrogen and non-flammable was more expensive to produce so remained tragically underutilized until after several spectacular dirigible disasters, including the *Hindenburg* in 1937. By that time the fascination with large dirigibles was on the wane and larger, heavier-than-air craft were in ascendancy. But this is many leaps ahead of our story. We need to return to the English Franciscan monastery of Roger Bacon and pick up the trail of heavier-than-air flight design.

In 1250, Bacon completed a book titled “Secrets of Art and Nature’’ in which he makes the first known reference to a flying machine with “artificial wings made to beat the aire’’, known today as an ornithopter (bird-like craft). (Taylor & Mondey, p.8) However, it was Leonardo da Vinci, the versatile mathematician, painter, sculptor, architect and engineer and musician who made the first detailed analysis of the mechanics of flight. He studied birds in flight and made drawings to show his ideas on flight, including several sketches of flapping wing planes and ornithopters which he felt a human could operate. Da Vinci assumed that man’s muscular power was adequate for this purpose. Except for their reliance on human-powered flapping, da Vinci’s designs look remarkably like modern lightweight aircraft.

Following da Vinci, many inventors tried to make ornithopters, the most successful being Robert Hooke in England about 1650. Hooke claimed to succeed in flying, but he also wrote of the great difficulty in remaining in the air. None of the early experimenters realized that the human body is not built for bird-like flying. The human heart is only 0.5 percent of total body weight, whereas that of the golden eagle is 8 percent and that of the hummingbird up to 22 percent. Compared with man's normal heartbeat of 70 times per minute, even that of a sparrow throbs at an astounding 800 times per minute in flight. The limitations of human physiology were spelled out in 1680 by the Italian Giovanni Borelli. His *De Motu Animalium* describes at length why man could never hope to sustain his weight in the air *without mechanical assistance* . (Taylor and Munson, p.11) Borelli's assessment was later confirmed by an American engineer, Octave Chanute, who in his 1894 publication *Progress in Flying Machines* , stated that man could not develop sufficient power to fly with only his arms and legs. (Taylor and Munson, p.45). Chanute was a railway engineer whose work on steam and other engines proved a valuable guide to the Wright brothers. However, as we shall see, Borelli proved a much more accurate forecaster, for, less than 100 years after Chanute's publication, man flew substantial distances using the power of his legs and mechanical, but not motorized assistance.

Prior to 1800 there were few attempts at flight with heavier-than-air craft. The designs of Bacon, da Vinci, Hooke and others did not prove feasible. The most promising work—that of da Vinci—was not even published until late in the 19th century. (Taylor & Munson, p. 34) The man now recognized as the "father of aeronautics'', Sir George Cayley, was an English inventer and student of flight who unknowingly retraced much of da Vinci's path. Cayley, however, made a major breakthrough in aircraft design. He decided that it would be possible to make a plane fly through air if: 1. the plane were light enough, 2. the air could be forced against its wings by moving the plane through the air, and 3. stability could be provided by placement of crossed vertical and horizontal "tail'' wings. By using diagonal bracing to reinforce the wings and body of the craft, Cayley was able to greatly reduce the weight. Moving the ship through the air was to be accomplished by a propeller driven engine. Cayley even designed a new lightweight engine, but he never built and applied it. However, he did construct successful gliders and significant advanced understanding of flight theories of lift and drag. His separation of the means of propulsion from the aircraft itself pointed the way for later developments after his death in 1857.

Little more need be covered here about early aircraft. Immediately after Cayley, many experimenters built models to which small engines were attached for flight. The four forces acting on a craft: lift, drag, gravity and thrust were reasonably understood. All that remained was for development of an engine of sufficient power and lightness to provide the needed thrust to put a manned glider into flight. The Wright brothers in 1903 had the honor of being the first to achieve "true flight''— *powered, sustained* and *controlled* .

———

Determining Power Output

Students will, no doubt, be interested in the actual power output of a human body and their own output for familiar tasks. A calculating exercise is provided among the suggested classroom activities. However, the table below may prove helpful for students who are not familiar with the metric (MKS or SI) system of measurement.

Quantity	U.S. System	Metric System
1. gravity	32 ft/sec2	9.8m/sec2
2. mass	slugs (lb/32)	kilograms
3. weight (mg)	pounds	newtons
4. force	pounds	newtons
5. distance	feet	meters
6. time	seconds	seconds
7. work (=f x d)	footpounds	joules

8. Power (=w/t) horsepower watts
one horsepower = 550 foot pounds per second one horsepower = 746 watts

VI. Physics of Flight—Four Forces

Studies by da Vinci, Newton, Cayley and others produced a clear picture of the basic forces which act upon objects in flight, whether kite, bird or plane. It will be helpful for students to understand these forces—gravity, lift, drag, and thrust—and their relationships to each other as they trace the Daedalus odyssey.

Weight is the force produced by earth's gravity which tends to move all mass toward its center. Gravity acts on an object in flight just as it does on the object on the ground—producing a downward pull or force. (Weight = mass of the object x acceleration due to gravity)

Lift is a force which acts against the weight to push it upward. When lift is greater than weight, the object rises; when weight is greater than lift, it sinks. Lift (leaving aside considerations of buoyancy) acts only on objects in motion and it is the shape and tilt of the object which influences the amount of the lift.

Thrust is the force produced by flapping wings, a propeller, jet engine or rocket. For a kite, thrust is provided by the pull of the string (see diagram in figure 2). Thrust, the forward push or pull, acts only on an object in motion.

Drag if the force produced by the resistance of the air against the moving object. It, too, acts only on an object in motion and can be represented in a diagram as a backward force or pull.

Figure 2 provides simple sketches of a bird, kite and airplane with the four forces drawn as arrows (or "vectors''). The most fundamental principle of true flight can be clearly stated in terms of the forces: A kite, bird or airplane is in level, steady flight when its *lift equals its weight* and its *drag equals its thrust* .

Air is the medium through which birds and planes fly. In order to fly a plane is dependent upon surfaces with which to support itself in the air. Such surfaces are called *airfoils* . Airfoils are surfaces designed to produce efficient lifting force—wings, tails and propellers are examples. Sir George Cayley, by building many models, learned a key lesson which most students have learned at one time or another with folded paper airplanes—some bodies projected through air give a large amount of lift. A properly designed body projected through the air in a horizontal direction will produce a net lifting force perpendicular to the horizontal direction.

(figure available in print form)
Figure 2: The four forces affecting flight of Birds, Kites, Planes.

VII. Human powered flight in the 20th century

> "The airplane is of course only a machine, but what an instrument of analysis! This instrument has shown us the oral face of the earth . . . Up here, observing man from our portholes, we find

ourselves judging him on a cosmic scale . . . *We find ourselves rereading our own history.* ''

—Antoine de Saint-Exupery (Canby, p.6) "Rereading history'' is really the underlying task of our Daedalus odyssey. What we seek to establish or perhaps simply remind ourselves of is the connectedness between human imagination and human powered flight. With Cayley's publishing in 1809 (Canby, p.16) of the first realistic theory of the airplane, a means was available for analyzing all previous attempts at flight and for scientifically pursuing all subsequent developments. Taking the four forces into account, we can go back even to the first Daedalus "flight'' and see that his thrust and lift devices were inadequate for the task of overcoming the burdens of his weight and drag. It is also possible to see why Cayley is the "father of the modern airplane''. Though he did not build a successful prototype, he made clear the obstacles to be overcome and even provided the design formula: lighten the ship's weight; make a rigid wing (airfoil) to provide lift; provide a separate mechanism (engine) to produce thrust; stabilize (and also reduce drag) with a tail assembly.

All that was needed after Cayley were relatively small advances in the airfoil and engine design and the modern airplane was born. Our story could end here with the triumphal inauguration of the era of motorized flight at Kitty Hawk. However, one final chapter in the Daedalus cycle must be accounted for. While the vast majority of aircraft design and development followed the route of harnessing ever larger engines to larger and more streamlined airfoils, another path of development pursued the design of radically increased lift and reducing weight to enable the thrust required to fit within the scale of output by a "humane engine''. Only in the past 25 years has the human powered aircraft come into its own, relying on advances in a combination of essential technologies: aerodynamics, propulsive, and structural.

A series of international competitions sponsored by a few organizations and individuals did much to stimulate human powered flight. The first great competition took place in France between 1912 and 1922, sponsored by the Peugeot company. It resulted in aircraft that were described more as "jumping bicycles''—the pilot pedaled hard to get up ground speed and then the craft would glide in the air for about 12 meters. Once airborn there was no way to add to the thrust. In 1935 German, Italian and Russian prizes were offered for the first human power flight around two posts set 500 meters apart. None of the prize money was claimed, but new designs were shown capable of several hundred meters of propeller driven flight if launched by catapult.

The most renowned competitions and the ones which have spurred significant technological progress have been sponsored by a British manufacturer, Henry Kremer. In 1959 he offered a prize of 5,000 pounds to the first entrant to fly around a one-mile, figure eight course under human power alone. 18 years passed and the prize money increased to 50,000 pounds before Bryan Allen of the United States successfully flew Paul MacCready's *Gossamer Condor* around such a circuit. Kremer then offered the largest prize in aviation history, 100,000 pounds for a human-powered flight across the English Channel. Again the winner was Allen, pedalling the *Gossamer Albatross* across the 21 mile strait on June 12,1979. Seeking to encourage smaller and faster craft, Kremer offered yet another prize, 20,000 pounds to the first contestant who would complete a 1,500 meter triangular course in less than 3 minutes—an average speed of nearly 20 miles per hour with some technically challenging turns. This prize was won in May, 1984 by Frank Scarabino in the *Monarch* , a craft designed and built at the Massachusetts Institute of Technology.

In each Kremer competition, the designers faced a common problem: how to reduce the power required by the aircraft to the amount available from a human being. This amount varies widely according to the person's age, training and motivation. A well-conditioned athlete can produce up to one kilowatt (about 1.3

horsepower) for short periods of time or a few hundred watts for several hours. (Drela and Langford, *Scientific American* , Nov'85)

Since the power required by an aircraft is the product of its aerodynamic drag and its velocity, low power can be obtained by building a craft with low drag and flying slowly. The wing is an aircraft's main aerodynamic surface. Since it creates most of the drag, its shape must be as efficient as possible. New materials such as graphite and graphite-epoxy have enabled builders to make large, lightweight fixed wings and by covering surfaces with mylar film drag can be minimized.

Following the successful capture of the Kremer prize in 1984, the MIT design team began to prepare for their ultimate challenge—the reenactment of the Daedalus flight from Crete. Preparations were extraordinary. To build and test the 70 pounds aircraft took 15,000 hours and one million dollars. Five athletes—bicycling champions—were selected and put through rigorous training and endurance tests. The pilot of the craft would pedal a mechanism which operated through two gear boxes and turned an 11-foot, superlight propeller to provide thrust for the craft. The length of the flight and low speed required that the operator maintain a high level of pedalling power for nearly five hours—not unlike running two back-to-back marathons. Even a new beverage was developed for the flight to replace the perspiration and minerals sweated off by the pilot.

Finally, at 7:06 A.M. on a sunny Saturday last April, the ultralight *Daedalus 88* was propelled down the runway of an airfield in Heraklion, Crete, bound for the volcanic island of Santorini 74 miles away. The pilot and "power'' of the plane was Kanellos Kanellopoulos, 31, winner of 14 Greek national cycling championships. Aided by a mild tailwind, the plane advanced at a graceful 18.9 miles per hour. Just three hours and 54 minutes after takeoff, the craft approached the beach of Santorini. Suddenly an offshore gust caught the craft bringing it up into a stall and snapping off its tail. The Daedalus plunged into the sea 30 feet from shore. Undaunted, Kanellopoulos swam to shore, the holder of three world human-power flight records:

1. Longest straight-line flight (74 miles).

2. Longest absolute distance flight (74 miles).

3. Duration aloft: 3 hours, 54 minutes. Perhaps, we might say, in the spirit of this unit, he also attained the record for completion of the longest known odyssey!

VIII. Classroom Activities

A *Reflections on the flight of Daedalus and Icarus*

One of the most famous depictions of the flight of Daedalus is the painting "Landscape with the Fall of Icarus'' by Pieter Brueghel, located in the Brussels Museum. A print of this painting should be placed in the classroom for students to observe and contemplate while reading the poems by William Carlos Williams and W.H. Auden which it inspired. {The Institute resource materials for this course will include a 35 mm slide of the painting.}

1. "Landscape with the fall of Icarus''

According to Brueghel
when Icarus fell
it was spring
a farmer was ploughing
his field
the whole pagentry
of the year was
awake tingling
near
the edge of the sea
concerned
with itself
sweating in the sun
that melted
the wing's wax
unsignificantly
off the coast
there was
a splash quite unnoticed
this was
Icarus drowning

—William Carlos Williams, 1962

2. "Musee des Beaux Arts''

About suffering they were never wrong,
The Old Masters: how well they understood
Its human position; how it takes place
While someone else is eating or opening a window or just walking dully along;
How, when the aged are reverently, passionately waiting
For the miraculous birth, there always must be
Children who did not specifically want it to happen, skating
On a pond at the edge of the wood:
They never forgot
That even the dreadful martyrdom must run its course
Anyhow in a corner, some intidy spot
Where the dogs go on with their doggy life and the torturer's horse
Scratches its innocent behind on a tree.
In Breughel's *Icarus* , for instance: how everything turns away
Quite leisurely from the disaster; the plowman may
Have heard the splash, the forsaken cry,
But for him it was not an important failure; the sun shone
As it had to on the white legs disappearing into the green
Water; and the expensive delicate ship that must have seen
Something amazing, a boy falling out of the sky,
Had somewhere to get to and sailed calmly on.

—W.H. Auden, 1938

3. In the Brueghel painting the central figure is a peasant plowing, and several other figures are more immediately noticeable than Icarus who, disappearing into the sea, is easy to miss in the lower right-hand corner. Equally ignored by the figures is a dead body in the woods.

Students should examine the painting carefully for details and understanding of the artist's perspective. After reading the two poems aloud at least twice as a group, the following questions should be raised in discussions:

a. Who are Daedalus and Icarus? Where are they going in the painting? Why?

b. Why did Icarus fall?

c. In Williams' interpretation of the Brueghel painting, what possible importance does he attach to the fact that "It was spring''?

d. Brueghel is one of "The Old Masters'' of whom Auden speaks in line 2 of his poem. What is it that the wise artist tells about human suffering?

e. Both Auden and Williams comment that in the painting Icarus' drowning seems to go unnoted by other figures in the scene. What clues does each poet offer about why this may be so?

4. Written Assignment: Compose your own response to the Brueghel painting in the form of a poem, story or brief essay. (Written assignment could be an overnight task with student works to be read aloud the next day.)

B. *A Chronology of the Daedalus Odyssey*

Rationale : Class construction of a chronology of the Daedalus Odyssey will be helpful for students from several standpoints:

First it should give an overview of the nearly 6,000 years of time under consideration.

Second, it may help reveal the subtle shifts from myth to legend to historical fact in the evolution of a particular technology (flight).

Third, it will readily be obvious that there are overlapping phases or ages in the evolution of human flight—in particular, both heavier-than-air and lighter-than-air developments were intertwined as the nature of air, the atmosphere, airflow, physical forces became more understood.

Procedure : A large chart should be posted on the wall with a timeline stretching from 3500B.C. to 1988A.D. Using references listed in the bibliography, encyclopedias, dictionaries and other sources, students should research and label on the timeline key events, people, inventions and achievements. Each student should write a brief description on a 3x5 file card and attach this to the timeline in the appropriate position. Teacher should provide models for the reports by presenting the timeline endcards for Daedalus Myth and Daedalus II flight.

Date: 3500B.C. (approximated)
Person: Daedalus, Greek craftsman and inventor
Event: Mythical flight by Daedalus from Crete using wax and feathers to make bird-like wings
Importance: First known mention of the idea of humanflight. Heroic vision of art and science combining to produce technology to expand human powers.
Date: April 23, 1986
Person: Kanellos Kanellopoulos, Greek cyclist
Event: 74-mile pedal-powered flight from Crete to Greek Island of Santorini in the “Daedalus 88’’ aircraft designed at Massachusetts Institute of Technology.
Importance: Successful enactment of the mythical Daedalus flight. Set 3 records for human-powered flight: longest, straight line flight, duration aloft (3 hrs, 54 min.), longest total distance (74 mil.)
Student topics should include: Icarus, King Bladud, Mo Ti Tzu, Archytas, Oliver of Malmesburg, tseung Kung Liang, Roger Bacon, Marco Polo, Leonardo da Vinci, Francesco de Lana, Giovanni Borelli, Joseph Montgolfier, Sir George Cayley, Henri Giffard, Henry Cavendish, T.S.C. Lowe, Otto Lilienthal, Samuel Langley, Orville and Wilbur Wright, the Peuguot Prize, Henry Kremer, Paul MacCready, Alan Tremml.

C. Personal Human-Power Factors

Objectives

1. To calculate horsepower developed during a specific physical activity
2. To propose ways to minimize the amount of work necessary to operate a bicycle and *Daedalus 88* .

Materials A bicycle, stop watch, scale, protractor, 100-ft tape measure, trigonometric tables.

Procedures

1. Pilots on *Daedalus 88* must develop and sustain 0.25 horsepower during the flight of the craft. In terms of a student's own experience, what does such an effort mean?
2. Power is the "rate of doing work'' or, Power=work/time. But work (W) equals force (F) applied times distance (D) moved, or W=FxD. Horsepower is one unit of power which is equivalent to 550 foot-pounds (work) per second.
3. Based on the above, the power required to raise a particular weight a given distance is:

Power=weight x distance traveled/time (P=WD/t)

Horsepower can be determined by dividing the result of this equation by 550 foot-pounds per second.

Example 1 : A student with a box of books totals 180 pounds. If the student carries the books up three flights of stairs (30 vertical feet) in 30 seconds, his horsepower can be calculated as:

P = 180 lb x 30 ft / 30 sec = 180 ft-lb/sec = (180 ft-lb/sec) / (550 ft-lb/sec) = 0.33 Horsepower

Example 2 : A cyclist and a bicycle weigh 200 pounds, the vertical distance traveled is 40 feet and the elapsed time of the ride is 60 seconds. Horsepower will be calculated as:

P=200 lbx40 ft/60 sec=133 ft-lb/sec =(133 ft-lb/sec)/(550 ft-lb/sec)= 0.24 Horsepower

4. Using either the stairs method or the bicycle method (have the rider go up a fairly long hill for which you can determine vertical rise by trigonometric methods), weigh,time and calculate your personal human-power rating. If available, enter your class data on a computer and generate a graph of the human-power profile of your class.
5. Try the experiment with cyclists who are in better or poorer physical shape. If student(s) are interested, have one or more try repeated runs and record data for sustained horsepower output.
6. Determine how training affects the output of horsepower. Speculate on factors that might limit the amount of power a person can develop/sustain. How might limiting factors be overcome. Relate class discussion to the Daedalus Project.
7. "Flight Check'': Have students write a scientific paper summarizing their findings and conclusions.

IX. Suggested Readings and Resources :

Bibliography for Teachers

Anderson, John D., Jr., *Introduction to Flight* , New York: McGraw-Hill, 1978.

Excellent introduction to the study of aerodynamics with brief treatment of the history of aviation as well as laws of physics and principles of flight.

Arey, Charles Kenneth, *Aeronautics* , New York: Macmillan Co., 1942.

Teachers guide to “elementary science for the air age’’. Charts, diagrams, student projects, glossary. A classic oldie but goodie!

Boyne, Walter J. , *The Smithsonian Book of Flight* , Washington, D.C.: Smithsonian Books, 1987.

Well written and lavishly illustrated single-volume history of flight covering the evolution of aviation technology from the Wright Flyer of 1903 to the Gossamer Condor of 1987. Includes photo of the Paul MacCready computer-assisted model of the ptertosaur, a reptile that flew by flapping its wings 70 million years ago.

Campbell, Joseph, *The Hero With a Thousand Faces* , Princeton: Princeton University Press, 1949; 2nd edition, 1968.

The classic study, through examination of another hero myths, of man’s eternal struggle for identity.

Canby, Courtlandt, *A History of Flight* , Boston: Van Nostrand, 1963.

Excellent chronology and illustrations.

Cohen, Rose N., *Flying High* , New York: Macmillan, 1942.

Anthology of aviation literature for junior and senior high readers. Good source for classic short stories and poems.

Gibbs-Smith, Charles Harvard, *Flight Through the Ages* , New York: Crowell, 1974.

Complete illustrated chronology from dreamers of early history to the age of space exploration; lacking in treatment of human-powered flight.

Grosser, Morton, Gossamer Odyssey: *The Triumph of Human Powered Flight* , New York: Houghton-Mifflin, 1984.

Detailed and lively account of the development of the Gossamer human powered planes by Paul MacCready and their successful capture of the human-powered flight records.

Hart, Ivor Blashker: *Mechanical Investigations of Leonardo da Vinci* , Berkeley: UCal press, 1963.

Detailed discussion of the genius of da Vinci designs for many purposes including flight.

Jane’s All the World’s Aircraft , London: Jane’s Publishing, Inc., 1983-84.

Published semi-annually, the definitive catalog of world aircraft providing photos and specifications. If it is flying, you will find it in Jane's!

Michels, Tim, *Solar Energy Utilization* , New York: Van Nostrand Reinhold Co., 1979.

Useful guide for discussion of potential of solar powered flight.

Robinson, Pearle Thurber, *Before You Fly* , New York:Holt, 1943.

Simplified explanation of the essentials of aeronautics. Helpful chapters on Laws of Physics and forces affecting flight.

Taylor, John W.R. and Munson, Kenneth, *History of Aviation* , New York: Crown Publishers, 1978.

One of several classroom reference texts covering the whole span of aviation history, providing over 1500 colorful illustrations and brief biographies of hundreds of famous designers and pilots. The first few chapters provide fascinating details of early myths, legends and disastrous attempts at flight.

Taylor, Michael J.H., *Fantastic flying Machines* , London: Jane's Publishing, Inc., 1983.

Broad historical reference, but noteworthy because of inclusion of chapter on glass fiber and foam construction and human-powered flight.

Taylor, Michael J. H. and Mondey, David, *Milestones of Flight* , London: Jane's Publishing, Inc., 1983.

Another excellent classroom reference including a thorough aviation chronology of milestones from 863 BC to the present.

Time-Life, *The Epic of Flight* , Alexandria: Time-Life Books, 1982.

23 volume reference set in typical Time-Life format presenting the glorious accomplishments of flying. Emphasis on 20th century; however,Volume 1, "The road to Kitty Hawk'', provides early legends and history.

Warner, Rex, *The Stories of the Greeks* , New York: Farrar, Straus & Firoux, 1967.

Complete guide to Greek mythology, written with clarity and brevity.

Readings for Students

(These books are recommended to provide easy access to the history and theories of flight for students. It is expected that students will also be challenged to read and explain newspaper and journal articles of considerably more focussed and technical nature. Student writing will cover a variety of styles from creative fiction to scientific essays. Models can be found among these and other books.)

Anderson, Lonzo, *Bag of Smoke* , New York: Viking, 1942.

A story of the Montgolfier brother's invention of the balloon. Easily readable, historically accurate, student project or storytelling stimulus.

Ardley, Neil, *Ar and flight* , New York: F. Watts, 1984.

Suggested activities for student projects to illustrate properties of air and how air can be used to make things fly.

Dwiggings, Donald, *Man-Powered Aircraft* , Blue Ridge Press, 1984.

Brief survey of history of human powered flight with coverage of Dr. Paul MacCready and his program.

Farmer, Penelope, *Daedalus and Icarus* , New York: HBJ, 1971.

47 page, illustrated, lively version of the Greek myth.

Highland, Harold J., *The How and Why Wonder Book of Flight* , New York: Grosset & Dunlap, 1967.

The title might put off some older students, but this is a useful and readable treatment of basic aerodynamic history and theory. Student project ideas are included.

Lewellen, John Bryan, *Birds & Planes-How They Fly* , New York: Crowell, 1958.

There are obvious similarities and not-so-obvious differences which this book explains and illustrates. Good starting point for student reports.

Macmillan, Norman, *Great Flights* , London: G.Bell, 1964.

236 pages, illustrated, famous flights and air adventurers from balloons to spacecraft. Unfortunately, won't help with recent 25 years' accomplishments.

Scarry, Huck, *Balloon Trip* , New Jersey: Prentice Hall, 1982.

This is a kids' book for adults, much like Richard Scarry's humorously illustrated books. Balloon facts and flight are interwoven with a story line and great pen & ink illustrations.

Wills, Maralys, *Manbirds* , New York: Prentice Hall, 1983.

Similar to the Dwiggins book above, a brief treatment of the history and development of human powered flight.

Zisfein, Melvin B., *Flight: Panorama of Aviation* , New York: Pantheon Books, 1981.

Illustrated history of flight from early theories to present time. Simplified drawings might encourage students to try their hands at illustrating their own reports.

Journal Articles for Teachers and Students

Ackerman-Blount, joan and Johnson, William Oscasr, "Winning into history,'' *Sports Illustrated* , v68-May 2'88 p32(8)

Report on the historic Daedalus II's 74 mile flight over the Aegean from viewpoint as athletic triumph.

Ashley, Steven, "88 pound pedal plane,'' *Popular Science* , v230-Feb'87 p70(7).

New technology of aircraft materials makes radical reduction of weight possible.

Barnes-Svarney, Patricia, “Flight attendant McCallin’s expertise crucial to Daedalus,’’ *Women’s Sport and Fitness* , v10-Mar’88 p101(1).

Lois McCallin was the one female among the five cyclists trained to fly the Daedalus. Her role was significant for the flight and for women in sports.

Drela, Mark and Langford, John S., “Human-powered flight,’’ *Scientific American* v253-Nov’85 p144(8).

Comprehensive article concerning the design of modern human powered aircraft.

“Flights of fancy,’’ *Life* , v11-June’88 p2(2).

Photographs of Daedalus II distance record in the Aegaen.

Groman, Christine, “On the wings of mythology,’’ *Time* , v131-May2,88 p67(1).

Report on the successful flight by Greek cyclist in the Daedalus II from Crete to island of Santorini.

Grogan, David, “Engineer John Langford and the Daedalus Project fly in the slipstream of a myth,’’ *People Weekly* , v29-Feb 29’68 p54(3).

Human interest interview with the director of the MIT project, typical *People* style.

Langford, John S., “Mach. 03 or bust,’’ *Technology Review* , v88-May/June 85 p66(8).

Langford, part of the design team for the Daedalus project describes the drive to set a record for human powered flight.

Peterson, Ivars, “On a wing and a pedal,’’ *Science News* , v133-April 30’88 p277(1).

Report on the Daedalus II flight.

Redcay, Jim, “Gossamer Albatross—Technological Wonder,’’ Bicycling, v27-Feb’86,p44(2).

Today’s reality of human bicycle powered flight was pure fantasy just 25 years ago. Redcay explains the advances in materials and technology which now make these flights possible.

Redcay, Jim, “The Gossamer Thinker,’’ *Bicycling* , v26-May’85, p344(7).

Interview with inventor, design engineer, aeronautical visionary Dr. Paul MacCready.

Siwolop, Sana, “Hot wax! The myth of daaedalus gets put to the test,’’ *Business Week* , v2938-Mar 24’86 p103(1)

MIT and the Smithsonian attempt to trace their journey with a high tech, pedal-powered aircraft.

“Superlight Flight’’, *Science Impact Letter* -Special Report, Vol.1, No. 11, April 1988.

Two page summary of emerging prospects for superlight, pilotless, high attitude aircraft with suggestion that either solar or microwave power will be the technology of the future. Questions about the practicality and viability of such aircraft are raised in the article by current human-power flight experts.

Wegener, Peter P. “The Science of Flight,’’ *American Scientist* , Vol. 74, May-June ‘86, pp.268-278.

Concise, illustrated treatment of the fundamentals of flight dynamics by YNHTI Professor Peter Wegener. Highly recommended for teacher background and for study by advanced students.

Videotapes

1. “Human Powered Flight’’, *NOVA* Special: 1987.
One-hour special aired on Public Television NOVA program in 1987. Covers the major developments during the past decade in human flight, including preparation for the historic daedalus II flight. **Highly recommended for class use**
2. “Flight of Imagination’’, Gossamer Ventures, 1981.
One hour documentary covering the story of the Gossamer Albatross project; won Emmy Award, 1981.
3. “Flight of the Gossamer Condor’’, Gossamer Ventures, 1979.
27-minute winner of the 1979 Academy Award for short documentaries.
4.”Sunflight Odyssey’’, Gossamer Ventures, 1982.
One-hour documentary on the solar airplane project under direction of Paul MacCready.