Introduction

This is a book about how to fly airplanes. As the subtitle suggests, the main topics are

- **Perceptions:** how to use your eyes, your ears, your fingertips, and the seat of your pants --- to gather the information you need.
- **Procedures:** how to use your hands and feet --- to make the airplane do what you want.
- **Principles:** how to organize your thinking --- to make your flying easier and safer.

Several of the ideas in this book will seem new to most pilots. The ideas are actually quite old and straightforward, but they have been not been covered by traditional pilot training. Like so many basic truths, they will seem obvious in retrospect.

For example, consider the question: “How does the altitude respond if you pull back on the yoke?” The key idea is there are two responses: pulling back causes a *short-term* response and a *long-term* response. It is quite easy and quite useful to recognize the difference between the two.

Similarly, there is an important distinction between flight at cruising speed and flight at approach speed: procedures which are appropriate in one regime are inconvenient --- or downright lethal --- in the other regime. This book will tell you how to do things right at high speeds, low speeds, and everywhere in between.

As a third example, consider the “pitch trim” wheel. What does it really do? Some pilots use it (as the name might suggest) to trim for a definite pitch attitude (which is a really bad idea). Other pilots use it to trim for a definite rate of climb (which is perhaps an even worse idea). Good pilots trim for a definite airspeed, or, better yet, a definite angle of attack.

The best pilots all seem to know these things implicitly. The purpose of this book is to make these things explicit --- to give them names and to draw pictures of them.

Some people may still be wondering: is it really necessary to learn new procedures, perceptions, and principles? After all, there are 700,000 pilots out there, most of whom seem to get by OK. The answer is simple: 2000 of those pilots had accidents last year. Many of those accidents would not have occurred if people had been taught the ideas put forward in this book.

* *Readership, Topics, and Goals*

This book is intended to appeal to pilots and everyone else who is interested in how airplanes behave. The idea is to concentrate on ideas that are useful in the cockpit, and to explain them as clearly as possible.

In addition to describing how the airplane behaves, this book describes in some detail *why* the airplane behaves that way. This may not be strictly necessary, but it is often very helpful, because: (1) Knowing why gives you more confidence that you are doing the right thing. (2) Knowing why helps you know what to expect in unusual situations. (3) Explanations that make sense are easier to remember than explanations that don’t make sense. Human beings hate being told to do something without any explanation. If they are not told the true explanations, they will make up their own pseudo-explanations. All too often these pseudo-explanations cover only the everyday situations; they go haywire when applied to unusual situations, let alone emergencies.

Here are just a few of the topics to be covered:

- What happens if you push or pull on the yoke a little?
- What happens if you open or close the throttle a little?
- What does the trim wheel really control, and why?
- What is the best way to escape from a spiral dive?
- What happens if you go outside the weight & balance envelope?
- What do the airflow and pressure patterns look like near a wing?
- Why is a skid more dangerous than a proper slip?

This is not meant to be an aerodynamics book. If you want to *build* airplanes, go read an aerodynamics book. If you want to *fly* airplanes, read this book.

Actually, there are two kinds of aerodynamics books on the market:

1. "Aerodynamics for engineers" --- The good news is that these books are typically quite detailed and reliable. The bad news is that even the simplest ideas are expressed in mathematical terms; you will need years and years of study in order to understand what is being said. The other bad news is that even if you can follow the math, it won't do you any good during flight. I don't do calculations in the cockpit, and you shouldn't either.

2. "Aerodynamics for pilots" --- Many of these books are bad news all around. They don't really tell you how to build an airplane, and they don't really tell you how to fly an airplane, either. They might tell you that angle of attack is important, but they don't tell you how to perceive angle of attack during flight, or how to control it. What's worse, many of the ideas in these books are just plain wrong.

   For example, nearly all of the "aerodynamics for pilots" books say a wing produces lift because it is curved on top and flat on the bottom. Alas, this isn't correct; it isn't even a useful approximation. We all know that airplanes can fly just fine upside down, which indicates that the difference in shape between top and bottom can't be all that crucial. Besides, some aircraft use symmetric airfoils (where the top is a mirror image of the bottom) and they work just fine.

Again, the purpose of this book is to explain how to fly an airplane. It concentrates on ideas that are useful in the cockpit. It explains things at a nontechnical level that should be accessible to almost everybody. Most people (including me) find the *picture* of an airflow pattern a lot easier to grasp than the equation that describes the airflow.

* *How to Use this Book*

I hope you will find these topics interesting... but this book is not *just* for entertainment: I find that the information presented here helps people fly the airplane better.

There is a saying that "practice makes perfect" -- but that's wrong. It's wrong in at least two ways.

For starters, the truth is that *practice makes permanent.* If you're practicing the wrong things, practice is worse than nothing. The key is to practice the right things. Learn the right procedures, then go practice them.

Secondly, practice without understanding may be useful preparation for routine situations, but nothing is ever entirely routine. Every airport is a little bit different, every airplane is a little bit different, and

you can never be entirely sure what to expect from the wind, weather, controllers, or other airplanes. Therefore you have to *understand* what you're doing, so you can improvise.

On the other side of the same coin, theoretical understanding without practice is not sufficient either. Although most of the time, things happen pretty slowly in the airplane, so you have time to think, there are a few situations where you have to get the timing right. There is no substitute for lots of practice, including recent practice, in these situations. This includes takeoffs, landings, and various foreseeable emergencies.

In critical situations where doing the right thing matters most, you will probably not have time to do any deep theoretical reasoning.

Furthermore, even in non-time-critical situations, there are some skills where you need the reliability that comes from habits based on disciplined practice. This includes scanning for conflicting traffic and scanning the instruments.

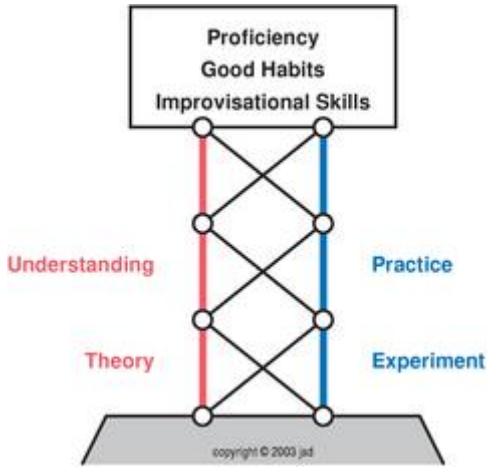

Figure 0.1: The Goals and Their Supports

Practice is not a substitute for understanding, nor vice versa. It's like the lattice shown in figure 0.1. The first stage consists of theoretical and experimental information learned from those who have gone before. Theory and experiment are cross-linked. That is the basis for the second stage, consisting of your own understanding and your own practice, which again are mutually reinforced by cross-linking. That in turn is the basis for deeper understanding and more refined practice. The ultimate goal comprises proficient performance, good habits, and improvisational skills.

Therefore, please read the book --- enjoy the book --- and also fly with an instructor and practice until the proper procedures become second nature.

See also the terms of sale in the appendix.

* *Non-Goals*

This book does not cover pilot/controller communications, or flight by reference to instruments. Those are topics for another book.

Also there exist many flying situations (e.g. mountain flying) that require specialized skills. These topics are not covered in conventional pilot training, and are not discussed here fully, if at all. You (the pilot) are entirely responsible for recognizing such situations, and for avoiding them unless/until you have the appropriate training and skill.

At the other extreme, this book does not provide ultra-elementary information such as the definition of “aileron”. Presumably you already know that, and/or you can easily and reliably find out on your own.

* *Acknowledgments*

First of all, I should thank my instructors, my students, and my fellow pilots who have taught me and helped me over the years. This book is for you.

In particular, thanks to Michael Madigan who was the first person to demonstrate to me that wise and safety-conscious people could be found flying light aircraft.

Also thanks to Darren Pleasance, who was born with wings but is patient with people who weren’t.

Many thanks to the members of the Monmouth Area Flying Club, especially Frank Fine who has contributed so much to so many worthy causes.

Special thanks to Howard Page, who was instrumental in convincing me that I ought to get a flight instructor certificate, and in persuading me to rewrite this material to make it accessible to a wider audience.

Peter Bradshaw, Denis Caravella, Richard Collins, Mark Drela, Paul Fuoss, Bob Gardner, David Joseph, Scott Kirkpatrick, Paul Mennen, David Messner, Harry Moore, Bob Parks, Philippe Spalart, and George Strickland provided important encouragement and suggested improvements in the drafts of the book.

* Bibliography

1.
Wolfgang Langewiesche, **Stick and Rudder**, McGraw-Hill (1944) ISBN 07 036240 8.
Level:
Non-technical, easy to read.
Intended Readership:
Pilots.
Remarks:
This is a classic. It should be required reading for all pilots.
Contents:
Wings, Some Air Sense, The Controls, The Basic Maneuvers, Getting Down, The Dangers of the Air, Some More Air Sense.
Strengths:
Emphasizes the importance of energy management (although by a different name).
Emphasizes the role of the stick in controlling airspeed.
Weaknesses:
Some sections are a bit dated, such as the (1944) plea to switch from taildraggers to tricycle gear. Also: page 34 reiterates the common misconception that a stalled wing cannot produce lift.

2.
Richard von Mises, **Theory of Flight**, (1945; Dover reprint 1959) ISBN 0 486 60541 8.
Level:
Technical. Uses calculus of complex variables.

Intended Readership:
Aerodynamicists, aircraft designers.
Remarks:
Another classic. I look here first for almost everything. Von Mises knows and loves airplanes, and is also a first class aerodynamicist.
Contents:
Section titles: Equilibrium and Steady Flow in the Atmosphere; The Wing; Propeller and Engine; Airplane Performance; Airplane Control and Stability.

3.

William K. Kershner, **The Student Pilot's Flight Manual**, Iowa State University.
Level:
Non-technical.
Intended Readership:
Student pilots.
Remarks:
Easy to read. Very good introductory text. Good review for private pilots.

4.

William K. Kershner, **The Advanced Pilot's Flight Manual**, Iowa State University (fifth edition, 1985) ISBN 0 8138 1300 X.
Level:
Non-technical.
Intended Readership:
Aspiring commercial pilots.
Remarks:
Fun to read. Recommended even for student pilots.
Contents:
Airplane Performance and Stability for Pilots; Checking Out in Advanced Models and Types; Emergencies and Unusual Situations; Advanced Navigation; High-Altitude Operations; Preparing for the Commercial Written and Flight Tests.
Strengths:
Covers a lot of good pilot-oriented material not covered elsewhere. Escapes many of the standard misconceptions.

5.

William K. Kershner, **The Flight Instructor's Manual**, Iowa State University (second edition, 1974) ISBN 0 8138 0653 6.
Level:
Non-technical.
Intended Readership:
Aspiring flight instructors.
Remarks:
Easy to read. Recommended even for non-instructors.
Strengths:
Very good discussion of spins, and a decent discussion of eights on pylons.

6.

William K. Kershner, **The Basic Aerobatics Manual**, Iowa State University (1987) ISBN 0 0138 0063 3.
Level:

Non-technical.
Intended Readership:
Pilots.
Remarks:
Easy to read. Recommended.
Strengths:
Contains an authoritative discussion of spins, including some test-flight data.

7.

Trevor Thom, **The Pilot's Manual --- The Airplane**, Center for Aviation Theory (1991). Available through AOPA.
Remarks:
Part of a three-volume set: Flight Training, The Airplane, Flight Operations.
Level:
Non-technical.
Intended Readership:
Pilots (private and commercial).
Strengths:
Covers a lot of topics not covered elsewhere. Escapes many of the standard misconceptions. Correctly emphasizes the role of angle of attack (not camber) in creating lift.
Weaknesses:
Falls prey to some of the standard misconceptions about separation vs. turbulence, P-factor, et cetera. Chapter 3 opens with a novel incorrect derivation of Bernoulli's principle.

8.

H. H. Hurt, Jr., **Aerodynamics for Naval Aviators**, U.S. Navy (1960, revised 1965) "NAVWEPS 00-80T-80".
Level:
Moderately technical. Uses equations.
Intended Readership:
Originally, Navy pilots.
Strengths:
The discussion of wings and lift is the best I've seen in pilot-oriented books, and is illustrated with data on real airfoils.
Weaknesses:
Later sections concentrate on high-speed flight and turbine engines --- not of primary importance to most general aviation pilots. The discussion of pitch stability is a disappointment: there is a huge discussion of secondary issues like bobweights and wing/tail interference, but not even a single mention of decalage. Naturally, the discussion of canards runs into trouble.

9.

Courtland D. Perkins and Robert E. Hage, **Airplane Performance, Stability, and Control**, Wiley (1949) ISBN 0 471 68046 X.
Level:
Technical. Uses calculus. Over 1000 equations.
Intended Readership:
Aircraft designers.
Remarks:
Standard reference. Emphasizes practical issues.

10.

E. L. Houghton and N. B. Carruthers, **Aerodynamics for Engineering Students**, Edward Arnold (1982) ISBN 0 7131 3433 X.
Level:
Technical. Uses calculus of complex variables.
Intended Readership:
Aircraft designers.
Remarks:
Less romantic but more modern than von Mises.

11.

H. C. “Skip” Smith, **The Illustrated Guide to Aerodynamics**, TAB Books (a division of McGraw-Hill) (second edition, 1992). ISBN 0 8306 3901 2.
Level:
Moderately technical. Algebra but no calculus.
Intended Readership:
Pilots.
Weaknesses:
Erroneous discussion of lift production.
Remarks:
Useful intermediate book: easier to read than reference 13; more coverage of topics important to pilots than reference 12.

12.

Peter P. Wegener, **What Makes Airplanes Fly?**, Springer-Verlag (1991) ISBN 0 387 97513 6.
Level:
Non-technical. A few simple equations here and there.
Intended Readership:
Liberal arts students.
Remarks:
Lots of historical background. Discusses the aerodynamics of everything from birds to automobiles to supersonic airliners. Discusses the economic impact of aviation.
Strengths:
Easy to read. Good discussion of circulation, Kutta condition, bound & trailing vortices. Nice table of form drag for various shapes.

13.

W. N. Hubin, **The Science of Flight : Pilot-oriented Aerodynamics**, Iowa State University Press (1992) ISBN 0 8138 0398 5.
Level:
Technical. Hundreds of equations; algebra but no calculus.
Intended Readership:
Pilots.
Contents:
Some Reasons and Some Terminology; Distances, Velocities, and Times; Force, Mass, and Moments; Static Properties of the Atmosphere; Subsonic Fluid Flow; Transonic and Supersonic Fluid Flow; Airspeeds; Determining Airfoil Properties; Airfoil Coefficients; A short History of Airfoils; Airfoils Compared; Properties of Wings; Lift, Drag, and Power for the Complete Aircraft; Aircraft Performance; Stalls, Dives, and Turns; Winds, Loops, Rolls, and Spins; Stability, Trim and Control; Aerodynamic Simulation: Tunnels and Computers; Aircraft Design Considerations.

Strengths:
A broader range of topics and a deeper level of detail than available in typical pilot-oriented books. Hundreds of annotated bibliographic citations. Clearly states that stability does not require a download on the tail.
Weaknesses:
On several graphs, the power curve is shown continuing below the stalling speed. Although the concept of circulation is introduced, the crucial connection is lost, namely the connection between circulation, air parcel arrival times, camber, and Bernoulli's principle. Also falls prey to P-factor misconceptions.
Remarks:
Despite the "pilot-oriented" subtitle, much of the material seems more oriented to designers than pilots. Recommended for readers who would like more mathematical detail beyond **See How It Flies** but don't quite need a Ph.D. in aerodynamics.

14.

FAA Advisory Circular AC 61-21A **Flight Training Handbook** (revised 1980). Available through the Government Printing Office; reprints available from pilot-oriented bookstores and supply shops.
Level:
Non-technical.
Intended Readership:
All pilots, including students.
Weaknesses:
Numerous errors, some of which are quite serious.
Remarks:
Superseded by reference 15 and to some extent by reference 16.

15.

FAA publication H-8083-3 **Airplane Flying Handbook** (revised 1999). Available through the Government Printing Office; reprints available from pilot-oriented bookstores and supply shops.
Level:
Non-technical.
Intended Readership:
All pilots, including students.
Weaknesses:
Numerous errors, some of which are quite serious. Superficial coverage of many topics.
Remarks:
Since this the "official" book, other writers feel entitled (or even obliged) to repeat what it says, errors and all.

16.

FAA Advisory Circular AC 61-23C, **Pilot's Handbook of Aeronautical Knowledge** (revised 1997). Available through the Government Printing Office; reprints available from pilot-oriented bookstores and supply shops.
Level:
Non-technical.
Intended Readership:
All pilots, including students.
Weaknesses:
Even more full of errors than reference 14.

17.

FAA Advisory Circular AC 61-27C, **Instrument Flying Handbook** (revised 2001). Available through the Government Printing Office; reprints available from pilot-oriented bookstores and supply shops.
Level:
Non-technical.
Intended Readership:
All pilots, including students.
Weaknesses:
Many, including erroneous discussion of spiral dives.

18.

John Roncz, a series of articles in *Sport Aviation*, appearing monthly from April 1990 to February 1991.
Level:
Minimally technical. Uses simple equations as needed.
Intended Readership:
The typical builder/pilot in the Experimental Aircraft Association.
Contents:
Recounts the design of a homebuilt aircraft, step by step. Includes spreadsheet programs to help with the design.

19.

James S. Bowman, Jr., “Summary of Spin Technology as Related to Light General-Aviation Airplanes”, NASA report TN D-6575 (1971).

20.

Sanger M. Burk, Jr., James S. Bowman, Jr., and William L. White, “Spin-Tunnel Investigation of the Spinning Characteristics of Typical Single-Engine General Aviation Airplane Designs”, NASA report (1977).

21.

Joseph R. Chambers and Sue B. Grafton, “Aerodynamic Characteristics of Airplanes at High Angles of Attack”, NASA report (1977).

22.

Peter Bradshaw, “Effects of Streamline Curvature on Turbulent Flow”, NATO Advisory Group for Aerospace Research and Development AGARDograph No. 169 (1973).
Level:
Technical.
Intended Readership:
Aerodynamicists.
Remarks:
Contains an authoritative discussion of the physics behind the Coanda effect.

23.

Ira H. Abbot and Albert E. von Doenhoff, **Theory of Wing Sections**, Dover (1949; reprinted 1958) ISBN 0 486 60586 8.
Level:
Main part is technical. Uses calculus of complex variables.

Intended Readership:
Aircraft designers.
Contents:
Really two books in one: a 300-page theory book, plus a 400-page “appendix” containing wind-tunnel data on NACA airfoils.
Remarks:
Many people buy it for the appendix.
Strengths:
Authoritative.

24.

Robert T. Jones, **Wing Theory**, Princeton U. Press (1990) ISBN 0 691 08536 6.
Level:
Technical. Uses calculus of complex variables.
Intended Readership:
Aerodynamicists.
Strengths:
Suggests extending Zhukovsky theory by using *compositions* of Zhukovsky-like transformations, which is definitely an advance over the product forms (with non-intuitive side conditions) used since the days of the pioneers (von Kàrmàn & Trefftz, von Mises). Advocates playing with airfoil sections on your PC.
Weaknesses:
Disorganized. Spotty selection of topics. Programs are buggy and inelegant.
Remarks:
Contains some interesting wrinkles, such as the lift-to-drag curves for the forward wing of the *Voyager* aircraft that flew around the world without refueling. The author clearly is a worker in the field, not just a spectator.

25.

Richard P. Feynman, Robert B. Leighton, and Matthew Sands, **The Feynman Lectures on Physics**. Addison-Wesley (1970) ISBN: 0201021153.
Level:
Progresses from introductory to technical. Intended readership: Undergraduate physics and engineering majors. Also read, re-read, and revered by Nobel prizewinners.
Strengths:
A classic. Brilliant, incisive, elegant. It will teach you how to think like a physicist.
Weaknesses:
It’s like an SR-71, not like a C-152. Some people find it too demanding.
Remarks:
A physicist’s physics book.
Contents:
Volume I: Laws of motion, thermodynamics, et cetera. Volume II: Electricity, magnetism, fluid flow, et cetera. Volume III: Quantum mechanics.

22 About the Book

The text of this book was prepared using:

- the TeX typesetting system created by Donald Knuth
- the LaTeX document preparation macros by Leslie Lamport
- the Emacs editor created by Richard Stallman and others
- the Computer Modern typeface also by Donald Knuth

I created the airflow diagrams using a simulation program to evaluate the fluid-dynamic equations of motion. I scanned the chart in figure 14.1. I drew the rest of the figures, line by line, as digital originals, using a combination of drawtool (a descendant of Idraw) and Adobe Illustrator. They are not "clip art".

22.0.1 Notice --- Instructions --- Terms of Sale

The purpose of this book is to express some of my ideas and opinions. The suitability of this book for any other purpose is expressly disclaimed. This book comes with no warranty whatsoever.

It is foreseen that you may wish to take action based on some of these ideas and opinions. Such action is entirely at your own risk. You should be aware that aviation involves risks, some of which are irreducible, and some of which can be greatly reduced by careful piloting.

Some care has been taken with this book, in the hopes that it will dispel more errors and misconceptions than it creates. However, nothing in this world is perfect, and you are warned that this book is neither 100% complete nor 100% error-free.

Before taking any potentially hazardous action, obtain and understand all available information on the subject. Do not use this book as a substitute for skilled professional flight instruction.

In no case will the author or publisher be liable for any direct, indirect, secondary, or consequential damages. In no case will the author or publisher be liable for any amount exceeding the normal price of this book. These terms are needed for the protection of the author and publisher. They shall not be construed to limit or exclude any other protections the author or publisher may have. If any of these protections is found invalid, the others shall remain in force.

22.1 About the Web Site

I have made essentially all of this book available on the World Wide Web. You can find it at http://www.av8n.com/how/.

The HTML was prepared from the LaTeX sources using HeVeA, plus some custom post-processing.

If you are having trouble downloading or viewing this book, please read the "troubleshooting" section below.

Many readers have provided valuable feedback about the parts they liked and the parts that needed fixing. Many sections were written in response to readers' requests for more information on certain topics. If you have questions or comments, you can send email to <jsd@av8n.com>.

22.2 Configuring and Troubleshooting your Browser

When viewing this book there are a couple of things that could go wrong:

1. Every so often I hear from somebody who observes that one or more of the chapters is truncated: it just stops in mid-sentence. This happens because of a problem in your web browser, probably a memory shortage. If this happens to you, you should try the following things:
    - Hit the "Reload" button on your browser. This probably won't help, but it's easy to do, so you might as well try it.
    - Clear your browser's disk-cache and memory-cache. On some browsers this involves clicking on Edit --- Preferences --- Advanced --- Cache --- Clear. This will probably do the trick. While you're at it, make sure the caches have a reasonable size (at least 3000 kB memory, 5000 kB disk).
    - Terminate and restart your browser.
    - Get rid of some of the other processes running on your computer and try again.
    - Make sure your computer's virtual memory system is configured properly, and is using a disk that has plenty of free space. Delete some junk files if necessary. Try again.
    - Shut down and restart your computer, then try again.
    - Install a current version of the browser, then try again. The older versions seem to be much less robust.

    If all that doesn't work, consult your local computer guru. There is nothing I can do to help, other than rewriting the book, and I'm not going to do that.

2. In your browser, the following should look like Greek letters: "γπ". If they look like "gamma" and "pi" then all is well. If they look like Roman letters such as "g" and "p" then your browser has not properly loaded the symbol fonts. To fix this please refer to the font-fixing notes.

22.3 Search This Site

Coming soon.

* About the Author

John Denker was an undergrad at Caltech. During his junior year, he founded a successful small software and electronics company which did pioneering work in many fields including security systems, Hollywood special effects, hand-held electronic games, and video games. Also while still an undergrad, he created and taught a course at Caltech: "Designing with Microprocessors".

His doctoral research at Cornell examined the properties of a gas of hydrogen atoms at temperatures only a few thousandths of a degree above absolute zero, and showed that quantum spin transport and long-lived "spin wave" resonances occur in this dilute Bose gas. Other research concerned the design of ultra-low-noise measuring devices, in which the fundamental quantum-mechanical limitations play an important role.

Dr. Denker joined AT&T Bell Laboratories and worked there for many years, serving in roles including Distinguished Member of Technical Staff, Department Head, and Division Manager. His research interests include computer security, internet telephony, and "neural networks" – combining ideas from biology, physics, computer science, and statistics in order to devise new types of information

processing systems. He has also invented novel low-energy “adiabatic” computing systems.

In 1986-87 he was Visiting Professor at the Institute for Theoretical Physics (University of California, Santa Barbara). He has served on the organizing committee of several major scientific conferences.

He holds numerous patents and has written over 50 research papers and one book chapter, and edited the book **Neural Networks for Computing**. He has lectured widely.

He is well known as a prankster and prototypical mad scientist. Some of his exploits were featured in the films “Real Genius” and “The Age Seeking for Genius”, as well as in publications such as “Time” and “IEEE Spectrum”.

John Denker is certified as a Commercial Pilot, Flight Instructor, and Ground Instructor. He is an FAA Aviation Safety Counselor. He is a past member of the board of trustees of the Monmouth Area Flying Club, and a past member of the National Research Council Committee on Commercial Aviation Security.