

Flight Dynamics by Tom Goodrick

**FLIGHT DYNAMICS FOR
MICROSOFT FLIGHT SIMULATOR**

By Tom Goodrick

Abacus "We Fly The World"

Flight Dynamics by Tom Goodrick

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Preface

This article is intended to help you enjoy the use of your Microsoft Flight Simulator software. To get the full benefit of the text, you should download the free Flight Dynamics Editor (FDEditor) program that is described throughout this article.

To download this program, go onto the Internet and go to the website <http://www.FlightSimDownloads.com/premier/premdown.htm>

We'll assume that you have this program available to use for reference. You may also want to go to my own web site at <http://home.earthlink.net/~tgoodrick> and download one or more free aircraft that have been developed using FDEditor. You can then use FDEditor to look at the data in the .air files of those planes. In this article I have used some math but only at the level of basic algebra. Some relations are more clearly stated in math than in words.

Today, FS98 has been replaced by FS2000 for many simmers with fast computers. However, the aircraft designed for use with FS98 can be flown in FS2000 with no conversion. For the most part, when you see "FS98" in this book, you can assume it applies to FS2000. It would seem likely you can edit the .air file of an FS2000 aircraft using FDEditor.

About the Author

The author has a Bachelor of Aeronautical Engineering Degree granted by the University of Minnesota in 1966. He worked from 1967 to 1989 as a civilian for the US Army at the Natick Research, Engineering and Development Center in Natick, Massachusetts where his duties involved aerodynamics and flight mechanics pertaining to parachutes, airdrop systems and transport aircraft related to airdrop missions. He specialized for several years in the analysis of gliding parachutes. From 1989 to his retirement in 1997, he worked for NASA at the George C Marshall Space Flight Center near Huntsville, Alabama where his duties were aerodynamics and flight mechanics pertaining to recovery systems, launch systems, hypersonic aerobrakes and hypersonic design of vehicles entering the atmosphere. He has published numerous technical reports and papers under the name of T F Goodrick. He has presented papers at symposia of the American Institute of Aeronautics and Astronautics (AIAA) and the International Aerospace Federation (IAF). Among his accomplishments are development of a flight dynamics simulation for gliding parachutes and a 3D rotating Earth sim for space vehicles orbiting the earth and entering the atmosphere to fly to a particular place for a landing. He is a licensed pilot, currently inactive.

INTRODUCTION

Microsoft Flight Simulator is an excellent tool for exploring the world of flight. Whether you have pilot experience or not, you can climb into the cockpit and fly a plane - indeed any of hundreds of planes ranging from simple four-place fixed-gear aircraft such as the Cessna Skylane or the Piper Dakota, to roaring Mach busters like the Concorde or the Space Shuttle Orbiter. Of course you will need to develop some experience before tackling some of the faster aircraft. But, that's the point of this Simulator. You can sit at home and try the different aircraft finding the ones you can work with and developing experience with different flight problems - venturing to new places around the world, flying in darkness and bad weather, etc.

Sooner or later, you will discover that there are many free aircraft available by downloading from various web sites. While most of these look great with high detail, few of them fly the same way the real aircraft does. If you have some information specific to the airplane and want to make it fly more realistically, you can use FDEditor by Abacus to fix the .air file for the aircraft. You also need a little knowledge of aerodynamics and flight mechanics to change the flight dynamics properties of the aircraft. This may be necessary because, when you convert an aircraft from an old FS format to a new one, many problems suddenly appear that the original designer never saw. Two common problems are bouncing while landing and divergent pitch behavior in flight causing the nose to oscillate up and down and finally go out of control. The purpose of this book is to give you enough information so you can fix most of these problems. Note that you can refer to the FDE parameter list in the Appendix for the identification of parameters discussed in the text. That list shows the wording used in FDE and the order of appearance.

It is important to realize that the long list of data item descriptions in FDEditor is not a list guaranteed to be exactly correct. There are other flight dynamics editors but they cannot guarantee exact correctness either. Why? Microsoft has not released any official descriptions of the contents of the flight dynamics file. Some of the elements in the list have been deciphered by people with inside knowledge but there is no basis for this speculation except for the exactness of some terms. Most of the information came from the shared knowledge of people like the author who have been testing these inputs for years making notes of which ones do this and which do that. This isn't the usual way of getting the job done, but we are forced to this because, while Microsoft owns the rights not only to FS98 but to the aircraft conversion program and to the original design programs, they have chosen not to reveal any of the technical details of this area.

Fixing the View

A common problem that many people find with FS aircraft is the restricted view out the windows - especially straight ahead trying to see the runway on final approach. There are a set of three coordinates in inches called Cockpit View but these set the view point only for looking out the diagonal or side windows. They are often useful because it is important to see the airport beside you when flying parallel to the runway on the downwind leg of a traffic pattern. In some cases like the original Learjet 45, the designers made it impossible to do this simple task. The view they give is from a short pilot sitting rigidly behind the wheel. Now even a dumb short pilot is going to raise himself up as he looks out the side window to find the runway. Raising the point of view solves this problem. However, the most common view problem is looking out the front window on final and not seeing the runway while descending on a normal ILS glide slope. This is solved by changing the Wing Angle of Incidence in the wing data section near the end of the .air file data list. FS98 is the first version having this parameter. All aircraft in FS98 are given -1 degree for this value by default. That means when the plane is level the wing would have an angle of attack of negative one degree. When flying final typically at 10 degrees angle of attack, the default plane is pitched upward another degree. Most wings on most real aircraft have a slight positive angle of incidence - a few degrees. If you enter +4 degrees for this wing angle, then on final approach at 10 degrees angle of attack, the plane will be pitched above the flight path only 6 degrees making it easier to see the runway over the panel. All aircraft on the author's web site are carefully adjusted for just the right wing angle. You'll find they also have a realistic looking attitude on final when viewed from the ground.

Each aircraft that you can fly in the Flight Simulator is represented by a set of files. These files set up the flight dynamics, the checklist, the sound, the panel layout, the physical model and the paint design for the aircraft. The file that pertains to flight dynamics is the file ending in .air so that is what we will call it. That is the file that can be changed by inputs using FDEditor. You must use caution in making changes because it is possible to really screw up the model so it won't fly right at all. It may leap off the ground while parked with the engine off! After reading this text, you should be able to change most of the things that can cause poor flight behavior such as improper weight, bouncing landing gear, low drag and even divergent pitch oscillations.

For those who may have trouble installing downloaded aircraft, the following is the file format required to install the aircraft named "A36" which is a Beechcraft A36 Bonanza from the author's site.

Folders and Files for Installed Aircraft in Flight Simulator

[Flight Simulator]

__Aircraft [Folder]

____A36 [Folder]

_____Aircraft.cfg [file naming aircraft and listing component files]

_____A36.air [the .air file containing flight dynamics properties]

_____A36.cfg [checklist file, optional]

_____Model [folder]

_____model.cfg [file naming model component files]

_____A36.mdl [file setting up body geometry]

_____Sound [folder]

_____sound.cfg [file showing how and when sounds are used]

_____anything.wav [optional files containing sounds]

_____Panel [folder]

_____panel.cfg [file naming and placing gauges on panel]

_____plane.bmp [file holding photo of panel background]

_____Texture [folder]

_____A36.0af [file containing paint info]

_____A36.1af [another file with paint info]

_____A36.2af [one of many more files with paint info, optional]

When the downloaded files are placed in folders like this, the aircraft is “installed” and can be flown by selecting it on the Aircraft Menu the next time you run FS. If it does not appear in the Aircraft Menu, then it may mean that panel.cfg refers to specific panels not in your system or to gauges that are not in your Gauges folder. Make sure you have downloaded and opened the free file FSCONV98.EXE from www.microsoft.com/games/fsim/downloads. You do not need to convert any aircraft labeled as “FS98 ready” but you do need to open this file to get many panels, gauges and to fix some FS98 bugs.

Flying and Editing

There is a technique for alternately flying and editing that works nice with a couple of quirks. To make an edit and then check it in flight, pause FS98 and then minimize it. Open the editor and select the air file for that plane. Make the edit and save the file. Then minimize the editor and activate FS98. However, before continuing the flight you must Select the Aircraft as though for the first time. Only then can you continue the flight with the changes in effect. You must be patient and should have a clear idea of what quality you are looking for. If testing for cruise speed, it may be several minutes before the aircraft becomes steady.

Getting Full Piston Power

With most piston aircraft there is an additional step. When first selected or re-selected, the engine power is not right. You cannot get full RPM at full throttle and, if flying, the RPM will start reduced below what was set. To get full power you must do the following:

- 1) Select Options and Preferences and Instruments.
- 2) Set Display Indicated Airspeed OFF. Click OK
- 3) Select Options and Preferences and Instruments again.
- 4) Set Display Indicated Airspeed ON. Click OK.

What does “Display Indicated Airspeed” have to do with power? Nothing. It’s just a quirk in the program! Ask Microsoft why it happens. Display Indicated Airspeed should always be on when you fly so you can control the aircraft properly at all altitudes. (This is explained later.)

Although the table of contents for this text looks a lot like some aeronautical engineering texts, rest assured only the most important aspects will be discussed in a practical way without resorting to very much math. We will show a few simple equations because they express important relationships. Understanding these relationships will help you decide how to approach some problems you encounter. We can’t just say “If this happens, do that” because there are too many weird things that can happen! By covering the basic theory, you will be prepared to figure out the solution.

When all FS98 aircraft are first designed, they are designed in a program called Flight Shop and are given initial flight dynamics specs in FS5.1, an early version of the Flight Simulator that was modified by the company that produced Flight Shop. When certain parameters like clean stall speed are entered into the FS5 flight dynamics, other parameters like max lift coefficient are computed and stored in the .air file. During successive conversions leading to FS98, some of these parameters are used to compute other parameters. Clean stall speed can only be changed in FS5. If you don’t have the FS5 flight model to work on, you are out of luck if the clean stall speed needs changing. There is an input in FDEditor for this value but changing it has no effect on flight. There are other cases where a series of parameters are computed based on a single entry in FS5 and stored in the .air file. If you change one of these parameters using FDEditor, you may be violating the laws of physics in relation to other parameters resulting in a plane that behaves strangely. Some people have identified tables of lift coefficients versus angle of attack, drag coefficients versus lift coefficients and drag coefficients versus Mach number. These are indeed in there and must be left alone to get realistic performance. They are modified during computation by scalars that are based on a particular design. To modify the table without knowing the scalar can really mess things up. Unless you really know what you are doing, as opposed to having seen such a table in some book, leave these tables alone.

Some aircraft you download, particularly if they are already in FS98 format, have problems you cannot fix without generating a brand new air file. Recently, the author downloaded a neat-looking ATR72 twin turboprop airliner that was so badly screwed up it was not really flying but was muscling its way through the sky with poor turn, pitch and speed control although the speeds were close to nominal. The designer had a good reputation so we did not look at the basic things until wasting time on the small things had little effect. The designer had used a wing area twice as large as the real aircraft yet all other dimensions and weights were realistic. As you will see below, weight and wing area are extremely important. By doubling the wing area, he had thrown way off all coefficient values and had given the plane an aspect ratio half what it should be which doubled the induced drag. All his efforts to achieve real flight speeds resulted in contortions of the parameters creating a mess that was too much trouble to solve. The aircraft was discarded. Recently, a solution has been found for these “unsolvable” problems. If you have FS5.1, you can take the airfile existing for any aircraft and copy it to a new file name that identifies it BUT is not the same as the “difficult” aircraft.. Then put in all the weights, dimensions and other parameters for the “difficult” aircraft including stall speeds and dynamic stability. Save it and convert it to FS98. Then copy just the .air file into the folder for the “difficult” aircraft replacing its air file (re-naming it appropriately). Discard the folder converted from FS5. In this way you replace the entire air file but keep the good looks of the “difficult” aircraft. This is just another example of the “impossible” taking a little longer!

There are some flukes or peculiar things in the Flight Sim calculations. Once when trying to get an F-105 to fly decently, the author was decrementing the area of the horizontal stabilizer which seemed large. The behavior was very erratic. Suddenly after entering a particular value, the behaviour was perfect. He reduced the area more and saw continued good behaviour. He then increased the area in smaller increments until it went bananas again. The cutoff was when the stabilizer area exceeded half the wing area! There must be something in a calculation that changes sign or becomes very large when that combination of values occurs. Note that for most aircraft, this fluke would not be a problem.

Aviation is a great industry in which the United States has played a major role. The more people participating in it to some degree, the better off we all are. Aviation is a strong element in our National Defense and in every aspect of business, transporting people and goods all over the world. Even our major league sports industry could not exist without speedy aircraft to move the teams around. If you have ever seen an airplane fly over while walking and wondered how it works or how you could learn to use an airplane, the Microsoft Flight Simulator gives you a chance to find out. This book should enhance the experience.

1. THE ATMOSPHERE

You may wonder why we need to study a little about the atmosphere. Certain features of the atmosphere produce peculiar effects in flight. We will present the basic aspects. Density, pressure and temperature vary with altitude in ways that have a significant effect on aircraft performance. The combined effects of engine thrust and aerodynamic forces make it possible and desirable to fly a constant indicated airspeed over a wide range of altitude. "Indicated Airspeed" is the airspeed shown on most airspeed dials in aircraft. It is more important for control of the aircraft than "True Airspeed" which is the actual speed of the aircraft with respect to the air mass. The variation of density with altitude causes true airspeed to be much greater than indicated airspeed at high altitude. This is why jets fly so fast. They don't fly very fast at all down at low altitudes. At 40,000 ft the true airspeed is about twice the indicated airspeed. The variation in temperature determines the speed of sound. "Mach Number" is the ratio of true airspeed to the speed of sound at the point where the airplane is. Since this speed decreases with altitude, it is easier to fly at high Mach numbers at high altitude. The pressure ratio is used by the altimeter to determine how high an airplane is. It also has a strong effect on the thrust put out by a jet engine. The ratio of thrust to sea level thrust is nearly equal to the ratio of pressure to sea level pressure. You'll see this can get as low as 15% at typical cruise altitudes.

Altitude Measurement

The plane's altimeter in the Flight Simulator works like the one in real aircraft. It directly sees ambient pressure and then finds the altitude that would correspond in a standard table like the one shown below. There is one control or adjustment to this. Under Aircraft / Aircraft Settings you can put in a barometric pressure for sea level that alters the altimeter's calibration so it gives a different altitude at a given pressure value. In real altimeters, you get into an aircraft on a given day and adjust the altimeter to read the correct height of the airport (which you always know from published information on maps, hangar doors, etc). If you call the tower for taxi clearance, you will also be given the barometric pressure reading and can crank this into your altimeter as an additional way of setting the pressure calibration for the day. This way works while flying between airports. Almost every contact you have with a ground station begins or ends with his telling you the barometric pressure. Airplanes have flown into the ground at night because the pilot did not reset his altimeter after flying into a low pressure area. There is an exception to this for jet aircraft. Anyone flying above 18,000 ft is required to reset his altimeter to 29.92. This is merely a way of assuring that all aircraft are properly separated vertically. Their actual height above sea level does not matter as much as their relative height. If two jets are flying in opposite directions on the same VOR radial reading altimeters for 1000 ft separation, we want them to have an actual

vertical separation of 1000 ft. We don't care if one is at 28,300 ft and the other is at 29,300 ft.

The author has tested the atmosphere in FS98 and has found it to be generally good and representative of the Standard Atmosphere. You can test this yourself by flying the Experimental Air Sampler or "XAS" aircraft downloaded from the author's web site. It flies up to 75,000 ft. You can fly slow enough to measure a temperature close to ambient. FS98 has an aerodynamic heating function that is reasonable but makes it difficult to read an outside temperature corresponding to still air. As the aircraft rams through it, the air heats up.

You have control over the temperature variation by setting temperature values at certain altitudes. The table only shows "standard" conditions. Daily and seasonal variations of tens of degrees can occur but it is generally very cold at the altitudes where jets cruise. You may want to use XAS to see what profile FS98 assumes between these values you set. It will affect the Mach number you get when cruising a jet. Generally, you must set a particular Mach number and take the true airspeed that results. It will vary from day to day in the real world.

The tables below give the variation in density and pressure ratios with altitude. The ratio in each case is of the local value to the sea level value. The temperature in Fahrenheit, the speed of sound (directly related to temperature) and the ratio of true to indicated airspeed are shown. Mach 0.8 is a typical cruise speed for jets. The indicated airspeed at constant Mach number gets low at high altitude.

The equation used to calculate the speed of sound is:

$$VSND = 29.07 * \text{SQRT}(459.4 + F)$$

where F is the Fahrenheit temperature. This same equation is used in FS98.

The FS98 table was determined by flying the Experimental Air Sampler at each altitude and measuring temperature, indicated and true airspeeds. A correction to temperature for indicated airspeed was made using a measurement at 10,000 ft.

1976 Standard Atmosphere Characteristics

Alt Feet	Dens Ratio	Pres Ratio	Temp F	SpdSound KTAS	Airspeed TAS/IAS	Mach 0.8 KIAS
0	1	1	59	662	1	530
2500	0.9289	0.9129	50	656	1.0376	506
5000	0.8617	0.8321	41	650	1.0773	483
7500	0.7983	0.7572	32	645	1.1192	461
10000	0.7386	0.6878	23	639	1.1636	439
15000	0.6295	0.5646	5	627	1.2604	398
20000	0.5332	0.4599	-12	615	1.3695	359
25000	0.4486	0.3716	-30	602	1.4930	323
30000	0.3747	0.2975	-48	590	1.6336	289
35000	0.3106	0.2360	-66	577	1.7943	257
40000	0.2471	0.1858	-67	574	2.0117	228
45000	0.1945	0.1462	-67	574	2.2675	202
50000	0.1531	0.1151	-67	574	2.5557	180
55000	0.1206	0.0906	-67	574	2.8796	159
60000	0.0914	0.0687	-67	574	3.3084	139
65000	0.0747	0.0562	-67	574	3.6576	126

Sea Level Ref Values: dens 0.002378 slugs per cu ft, pres=2116.23 psf

Source: US STANDARD ATMOSPHERE, 1976, NOAA, NASA, USAF

[Public Domain]

Measured FS98 Atmosphere Characteristics

Alt Feet	Dens Ratio	Temp F	SpdSound KTAS	Airspeed TAS/IAS	Mach 0.8 KIAS	
10000	0.7453	23	638	1.158	441	Temp Profile
20000	0.5354	-10	616	1.367	360	0 ft 59F
30000	0.3787	-40	595	1.625	293	20kft -12F
40000	0.2500	-56	584	2.000	234	36kft -65F
50000	0.1589	-52	587	2.508	187	60kft -70F
60000	0.1029	-45	592	3.117	152	

Temp correction: $(459.4+F120)*.9897415 - 459.4 = F0$

Note that the temp correction is only approximate. The temperature profile shown was set under “Weather / Temperature” for the flight.

Wind

Wind has two different effects on aircraft. A steady wind causes no extra force on the aircraft but produces a gradual drift of the flight path requiring the pilot to fly a different heading to compensate. A changing wind does indeed produce an extra force on the aircraft temporarily. A steady wind is a uniform motion of the air mass. Standing on the ground, we feel a wind as the air mass moves past us. An object immersed in the wind sees an initial force but the forces quickly balance, whether gravity-driven like a glider or driven by mechanical thrust. The object quickly feels no wind though it drifts steadily with the wind. It is not pushed by the wind anymore than a passenger in a cruising car is pushed by the car. Examples would be leaves falling from a tree or a kite after the string breaks. While attached to a tree, a leaf feels the force of the wind. Once broken off, the leaf quickly assumes nearly zero horizontal speed relative to the wind and we see it drift at wind speed as it descends. When you fly a kite, the kite develops a force through the string as you hold it standing firmly on the ground. If the string breaks, there is no force holding the kite up and it starts to drift with the wind while descending. After the string breaks, it is driven only by gravity like a glider.

Hence the only effect of steady wind on an airplane is drift shown on the ground track. The wings support the weight and the engine thrust balances the drag at some speed relative to the air that is entirely independent of the speed or direction with which the air mass moves past the earth. No instrument on the aircraft can detect windspeed directly. Today there are on-board computers that look at compass heading, true airspeed, groundspeed and course from GPS and estimate wind as the difference between the two velocities, groundspeed and airspeed.

In FS98 you can set different wind speeds and directions at any of several altitude levels. This is a situation commonly encountered in real life. Unfortunately, in FS98, the wind from one level holds constant until you climb to the next level where a new wind is set and its effect is experienced very suddenly. When the wind changes suddenly, the aircraft does experience strong aerodynamic forces which upset the flight significantly. This condition is called wind shear and does indeed occur in real life. Also, in real life there are gusts which FS98 does not simulate. (Turning on turbulence just shakes the aircraft in a rather strange way.) One typical setup has wind shears of 14, 24 and 40 knots at 2,000 ft, 12,000 ft and 24,000 ft giving winds at these altitudes that are reasonably representative. There are also directional changes. This gives your aircraft a little upset as you climb or descend just to prove that you're not in total control but are just along for the ride like any pilot!

Try this experiment in FS98. Set up a wind of zero speed from the surface to 2000 ft above ground. Set a wind of 20 knots from the south (180 degrees) from 2000 ft to 5000 ft. Note this is above sea level so if you use a high-elevation airport, adjust this to surface+2000 and +5000. Use any piston plane to make a flight, taking off and climbing to 1000 ft above ground, leveling and getting very steady, perhaps

with the autopilot. Make a full 360 degree turn at a bank angle of 30 degrees adjusting power to remain at constant altitude. (More power is needed to compensate for the bank angle.) Note that airspeed can remain steady during the turn. Now turn to a heading of 180 and climb to 3000 ft above the ground entering the high wind area. You will notice when you transition to the high wind area. You might play around with this because you'll find different effects depending on your heading at the transition. Flying south you gain 20 knots airspeed temporarily and flying north you lose 20 knots temporarily. Level off at 3000 ft and get steady just like you did before. You should find the same indicated airspeed. Perform another 360 degree turn as before. Notice that the airplane flies just like it did at the lower altitude. The only dynamic effect of the wind is when it changes suddenly. In a steady wind, direction of flight makes no difference unless you look at the ground. Your ground speed changes but your airspeed does not when you change direction in steady level flight.

2. DYNAMIC PRESSURE

“Dynamic Pressure” sounds like a big deal and it is in some respects. Without it, we couldn’t fly airplanes. Yet, it is not really a pressure that we feel, or the aircraft feels; but, all pressures we do feel are related to it, rather conveniently. It can be thought of as a difference between two very special pressures that arise when our airplane moves through the air. We have to give credit to Bernoulli who developed the law for steady motion of a fluid. He found that the sum of two terms is constant along any single streamline. (A streamline is a curved line the air never crosses.) The two terms are the static pressure, p_s and the dynamic pressure q . The sum of those terms is called the total pressure p_t . Hence his equation is simply $p_s + q = p_t$. If we pick a good clean streamline that goes from a long way in front of the aircraft and passes right next to the side of the aircraft, and if we adjust our thinking to see the plane moving through what had been still air until we came along, then you can think of the total pressure as the pressure on the streamline way ahead of the plane where nothing was going past it while the static pressure is the pressure it exerts on the side of the aircraft as it passes by at a speed V . Now we can rearrange the equation to show $q = p_t - p_s$. Now you see where we get the notion that dynamic pressure, q , is the difference between two pressures. You can feel these two pressures the next time you ride in a car with the window down. Cup your hand with the open cup mouth toward the front. You are feeling total pressure because you have captured some of the moving air and brought it to a stop in your hand. Moving your hand around you can feel the difference between p_t and p_s because p_s is the pressure on the side of your hand where the air is moving quickly past.

No Negative Pressure Allowed

Some aviation writers have used the term “negative pressure” when talking about the flow over a wing. This is a misunderstanding of terms. There never can be negative static pressure. However, engineers commonly use the term “pressure coefficient” which is defined as $(p - p_{s0})/q$ where p is some pressure measured somewhere on the surface of a body in the flow and p_{s0} is the freestream static pressure. It is possible to have a negative pressure coefficient. It simply means the local pressure is low compared to freestream static pressure.

Energy per Unit Volume

You may remember from physics class that a moving object has kinetic energy equal to $0.5 * m * V^2$ or half the product of the mass and the square of the velocity. Bernoulli found that you could treat moving air in a similar fashion. If you look at a small volume of air - we can call Q - that has a uniform velocity throughout, with a density of $d = m/Q$, you could express the energy of the moving air as $0.5 * m * V^2$ or, substituting Qd for m , you could say its energy is $0.5 * Qd * V^2$. Then if you want to generalize pick a "unit volume" where $Q=1$ and the equation is energy per unit volume equals $0.5 * d * V^2$ or half the density times the square of the velocity. That is all very nice. It happens to be the definition of dynamic pressure in Bernoulli's equation $q = 0.5 * d * V^2$:

$$p_t - p_s = 0.5 * d * V^2$$

Airspeed

Now we also see a way of physically measuring airspeed. We get the total pressure p_t from a tube called a "pitot" tube that sticks forward into the flow at some place away from the body where it sees undisturbed flow. We get static pressure p_s from a tube that sits flush with the side of the aircraft in relatively clean flow. We lead those pressures through plastic tubes to an instrument with a diaphragm that will measure the difference in those pressures and, bingo, we have measured q . Now if we just knew density d we could calculate and display airspeed from the equation:

$$V = \text{SQRT}(2 * q / d) = \text{SQRT}(2 * (p_t - p_s) / d)$$

Density is a tough thing to measure directly. The folks many years ago found that the solution was to calibrate the airspeed indicator using sea level density which we designate d_0 . Thus we see

$$VI = \text{SQRT}(2 * q / d_0)$$

when we look at the airspeed indicator. This is indicated airspeed. It is not the True Airspeed, V . But, it turns out we pilots are not interested in the truth in this case. Why? It is because all the forces that keep the aircraft in the air are related to q and, since VI really gives us a measurement of q , we can do best by using VI as a guide to flying the aircraft! The relation between indicated and true airspeed comes from the fact that the dynamic pressure must be equivalent:

$$0.5 * d_0 * VI^2 = 0.5 * d * VT^2 \text{ which leads to } (VI / VT)^2 = d / d_0 \text{ and}$$

$$VI = VT * \text{SQRT}(d / d_0) \text{ or, inversly, } VT = VI * \text{SQRT}(d_0 / d).$$

Many pilots consider that the airspeed indicator is the most important instrument in the panel. With all the neat gyro instruments and computer displays on today's panels it may be hard to believe. But, the fact is you can blank out (with a card) any other instrument on the panel and fly the airplane quite well. But, if you lose the airspeed, your chances of surviving the flight are slim. Try this in FS with any aircraft. Turn off the airspeed indicator either before or during a flight and then return to the airport and land the plane. It is challenging to say the least. In real life a frequent source of trouble is bugs making a home in either the static source or the total pressure tube. If people are smart enough to cover the total pressure tube to keep the bugs out, another common problem is people forgetting to remove the cover! There was one fatal crash at a local airport of a fancy little home-built which porpoised a little on takeoff so that the nose touched the runway after the gear came up. It had a pusher prop. The pilot made it into the air and flew around to make a landing. He spun into the ground turning final when he let his airspeed get too low. That plane had a pitot tube in the nose that must have been damaged by the contact with the runway.

That incident shows one very serious shortcoming of FS98. It does not simulate differential wing lift and, therefore, does not simulate one of the worst killers in aviation - the stall/spin. Take any FS aircraft up and try to make it go out of control so quickly that, from 500 ft altitude, you cannot recover. It is tough to do. But when you use too much or too little rudder turning final, a real plane can easily lose the lift on one wing while the other wing is still developing half the weight and - bingo! - you are upside down and going down in the wrong place at the wrong time. That's a big reason 50 to 90 people die in small airplane accidents every month in the US. If you don't believe that number, go to www.nts.gov and count the fatalities per month.

3. AERODYNAMIC FORCES

Returning to physics class a minute, we learned that kinetic energy can be made to do work if you set things up right. The way work is done on a body is by a force changing its motion. That's how we get dynamic pressure into the aerodynamic forces. It also makes sense if you think of a force as caused by a pressure difference acting over a certain exposed area. Classically, the aerodynamic forces have been defined as the following:

$$\text{Lift} = L = q * C_L * S$$

$$\text{Drag} = D = q * C_D * S$$

$$\text{Side force} = F_Y = q * C_Y * S$$

Also, by classical definition, drag acts in direct opposition to the velocity vector. This assigns it an exact direction relative to the flow. Lift acts perpendicular to drag in the vertical plane of the aircraft body (though that may be tilted relative to earth). Side force acts perpendicular to the plane formed by lift and drag. We can forget it because, in all steady flying, side force is zero. There are non-zero side forces in FS but we can only use steady forces to create useful relations.

These are rather simple equations and yet they deserve a little thought. No one can figure a way to determine theoretically the values of the coefficients C_D and C_L . They can be estimated based on similar shapes that have been studied. But, their exact values must always be determined by tests. Initial tests are performed in wind tunnels. D is measured and C_D is calculated as $D / q / S$ where S is a particular reference area chosen for the particular object. If the object is the whole airplane, S is always the projected area of the wing and equal to the span (tip to tip) times the average chord (front to back). But if the object being tested is a landing gear projecting below some surface, some other reference may be chosen such as the projected cross-section of the wheel. Later, when the landing gear is put on a particular airplane, the coefficient will be changed in proportion to that aircraft's wing area. For this reason, the magnitude of a drag coefficient for something like a landing gear has a different base of proportion than the magnitude of the drag coefficient for the whole aircraft. A similar situation exists for the flaps and the spoilers. In FS .air files, the inputs for drag coefficients for gear, flaps and spoilers are not necessarily in the same scale as the drag coefficient for the whole aircraft. There may be an internal conversion we don't see.

We won't go into aerodynamic moments except to say they have similar formulas with proportionality to q , to a coefficient, to a reference area S and to a reference length such as the chord or span of the wing.

Now we see why the dynamic pressure is so important to aircraft flight. All aerodynamic forces and moments depend on it. If we use Indicated Airspeed, we are assured that, at the same indicated speed, the forces and moments are the same regardless of altitude. Thus we can use indicated speed to avoid stall and to avoid breaking things. For any aircraft there is a turbulence penetration speed (V_a) at which it is safe to fly into moderate turbulence (typically twice the stall speed). There is also a Never Exceed speed (V_{ne} or V_{mo}) (typically three times the stall speed) above which the structure could fail. These are Indicated Airspeeds. There is a place for V_{ne} or V_{mo} for any aircraft in the FS98 .air file. Put the value 3 times clean stall speed in this input if you don't have a specific number from literature. Strangely, the default value for all converted aircraft is the true airspeed corresponding to whatever max Mach or MMO was set.

More Lift

The value of the lift coefficient is normally from zero to about 1.4 for most wings. It will go negative to provide support when you roll inverted and hold a large negative angle of attack. When flaps are deflected the maximum value can increase to as much as 2.2 or even as high as 3 with very fancy multi-component flaps and slats like you find on airliners. In wind tunnel tests of various wing airfoil shapes, the lift coefficient plotted versus angle of attack is very linear from zero through unity. Then above 1 it begins to curve and suddenly drops abruptly. In a technical sense, this abrupt reduction in CL is called "stall". In a practical sense, the highest value of CL before the abrupt drop determines the lowest speed at which the aircraft can maintain level flight. This is called the stall speed. The amount of increment in lift coefficient for the flaps on a particular aircraft is an input to the .air file. We will show later, under BASIC FLIGHT RELATIONS, how to calculate this value to achieve a certain stall speed. The value of the lift coefficient is directly proportional to the angle of attack. The horizontal stabilizer combined with the elevator are designed with the pitch control linkage so that, for any particular control setting (and for a given center of gravity location), there is stability about a particular angle of attack. This means the value of CL depends directly on the pitch control. That is your main way of controlling the forces on the aircraft.

More Drag

The total drag coefficient of an aircraft has two basic terms. One term is called the “zero lift drag coefficient”. It is a direct input in the .air file. It relates to the smoothness of the body and all components protruding into the flow. Such things as landing gear and spoilers add directly to this coefficient when deployed though they may first be scaled as mentioned above. The second term is the drag induced by lift. While lift is defined as perpendicular to drag and you’d think that means they are independent, the generation of lift tilts the flow field and induces an additional drag term. The term consists of the square of the lift divided by the wing aspect ratio. (CL^2 / AR). The total drag coefficient is generally written as;

$$CD = CD0 + CL^2 / (\pi * e * AR)$$

where $\pi = 3.14156$ and e has a value between 0.7 and 0.9 depending on wing planform shape. (A pure elliptical wing would theoretically get $e = 1$.) Earlier versions of FS used an “Induced Drag Scalar” which never seemed to work in a sensible way. It appears that FS98 uses the conventional induced drag term shown above. However, the parameter labeled “Main Wing Inv PI Aspect Ratio” is not correctly labeled. Its value is never close to this.

The aspect ratio is the ratio of the span to the chord of the wing: $AR = b / c$. You can also figure the aspect ratio from the relation $b*c = S$ so that

$$AR = b^2 / S.$$

As we have seen above, the wing area S is a very important parameter. For some very strange reason, it was not included as a basic input in the original Flight Shop program with which all FS aircraft are originally designed. The only inputs were the span (in inches) and the aspect ratio. Be sure to use span in feet and area in square feet when figuring aspect ratio from listed specs for an aircraft. In FS98 using FDE we can input any or all of these values, b , c or S .

4. EQUATIONS OF MOTION

Many people don't understand how a flight simulator does its computation to come up with continuously changing speed, attitude and position of the aircraft. There are no equations that give the changes in each angle or position coordinate at all times in response to a control setting. It is mathematically impossible to solve the differential equations of motion, in a general sense, to obtain such equations. The equations of motion are based on Newton's law: $\mathbf{F} = \mathbf{m} * \mathbf{a}$ except that we turn it around and say $\mathbf{a} = \mathbf{F} / \mathbf{m}$ where \mathbf{a} is the total acceleration which changes the velocity of the airplane, \mathbf{F} is the sum of all forces acting on the airplane and \mathbf{m} is the mass of the airplane. The problem is that, as we have just seen, the aero forces all contain squared velocity terms and all are oriented according to the instantaneous air velocity. Mathematically this poses extreme problems in solving these equations. To get a solution, you would perform mathematical integration on the right side of this equation to get the change in velocity. You would then perform another mathematical integration to get the change in position. As a young aeronautical engineer, the author thought nothing was truly impossible and he tackled these equations many times trying for a solution. He was only able to get a solution in two cases: 1) the case of an extraction parachute pulling cargo out of a large transport aircraft and 2) the case of a drag device descending vertically with no lateral forces. In the cargo extraction case there was only parachute drag to contend with and the cargo motion was purely horizontal within the aircraft. Thus the solution was an algebraic equation showing the speed and position of the cargo within the aircraft as it was pulled to the edge of the ramp. The case of vertical, one dimensional motion led to a very elegant solution that was completely worthless because nothing in the real world moves like that. Any falling object has both lift and drag though lift is poorly directed in many cases. As soon as you combine vertical and horizontal motion, the problem has no solution.

So how do we solve this "unsolvable" problem? We do it by approximating the process of mathematical integration. We calculate all the forces acting at one instant using the velocity vector v_1 which we know at that time. We also know the position vector p_1 at that time. We sum the forces to get the acceleration "a" and then find the new velocity vector v_2 as $v_2 = v_1 + a * dt$ where dt is a very short time interval. Then we get the new position vector as $p_2 = p_1 + (v_1 + v_2) * dt / 2$ in which we are really using the average velocity over the time interval dt .

There is a similar thing done with the angle but it is much more complicated and we won't express it here. Like forces produce accelerations, moments produce angular acceleration. However, unlike translational accelerations in which components on orthogonal axes are independent, rotational accelerations on all axes are coupled through functions involving differences in moments of inertia and rotational velocities. To make matters worse, the rotational orientation must be

transformed from local to an earth reference system in a complex mathematical process which involves additional integration equations. We'll leave that mess for some other day!

The bottom line in understanding the computation for a flight simulation is that, with only a knowledge of the situation over one short interval and with a flight being composed of many many intervals in which various control inputs take place, even engineers don't know everything that might happen on a given flight. In fact the concept of mathematical chaos was invented as people looked at flight simulations because, even with no control input after a given point, the motion can become so complex that it is impossible to predict the final outcome in exact terms - say the position, speed and attitude five minutes later. Think of the simulator as a little experiment box in which you can try different things and see what happens. All we can do is set some coefficients and other parameters that influence some forces that influence the motion. Then we stand back and watch what happens. Here's something to try. Take any aircraft in FS and fly it to a reasonably high altitude, get it into a climb and a steep bank, cut the power and then pause the flight. Look at the airplane from the spot plane view using the "Fixed" position and resume the flight with no further control inputs. Watch what happens. In such a case all we know for certain is that the plane will descend eventually and hit the ground because there is no power.

Wing Loading

If we take a moment to look at a dimensionless form of Newton's law, we will see one parameter that is most important to a realistic simulation of any particular aircraft. Using the form of Newton's law $\mathbf{a} = \mathbf{F} / \mathbf{m}$ divide both sides by g , the gravitational acceleration: $\mathbf{a} / g = \mathbf{F} / (\mathbf{m} * g) = \mathbf{F} / \mathbf{W}$. Now let's see what happens when we add aero, gravitational and thrust terms.

$$\mathbf{a} / g = \mathbf{q} * \mathbf{CD} / (\mathbf{W}/\mathbf{S}) * \mathbf{k1} + \mathbf{q} * \mathbf{CL} / (\mathbf{W}/\mathbf{S}) * \mathbf{k2} + \mathbf{1} * \mathbf{k3} + (\mathbf{T}/\mathbf{W}) * \mathbf{k4}$$

where the \mathbf{k} 's are used just to indicate coefficients for particular directional components of acceleration to be mathematically correct. Look what happened. Nowhere does \mathbf{W} appear by itself. In the aero terms it appears as \mathbf{W}/\mathbf{S} which is what we call the wing loading (weight over wing area). The gravity term is unity and the thrust term includes a ratio of thrust to weight. As I will prove later under BASIC FLIGHT RELATIONS, for most normal flight motion, \mathbf{T}/\mathbf{W} is very nearly equal to $\mathbf{CD} / \mathbf{CL}$. Now this equation looks even nicer:

$$\mathbf{a} / g = (\mathbf{q} / (\mathbf{W}/\mathbf{S})) * (\mathbf{k1} * \mathbf{CD} + \mathbf{k2} * \mathbf{CL}) + \mathbf{k3} + (\mathbf{CD} / \mathbf{CL}) * \mathbf{k4}$$

If you shut off thrust and just glide, the last term drops out. Note also that the difference $\mathbf{T}/\mathbf{W} > \mathbf{CD} / \mathbf{CL}$ is what makes a plane climb. But it illustrates the point that \mathbf{W}/\mathbf{S} or wing loading is the single most important factor in determining

performance. When you find that speed of a plane is too fast or slow compared to what you expect, check weight and wing area first. Sometimes the solution is simply to enter the correct values. However, when the designer used the wrong wing area from the beginning, all CD and CL values will be messed up. You may have to return to FS5 for a fresh .air file.

5. BASIC FLIGHT RELATIONS

In aeronautical engineering texts, there are many complex mathematical expressions. However, the two most important relations can be expressed very simply. As discussed above, the equations of motion for any aircraft are generally unsolvable. But, if you look just at steady-state conditions where all accelerations are zero, meaning that all forces and moments are balanced, there are several equations that can be derived. Probably the two most important and useful come from the simple relations that, in steady level cruising flight, lift balances weight or $L = W$ and drag balances thrust or $D = T$. These equations result from the definitions of lift and drag. Drag must oppose the velocity which is purely horizontal if you are in steady level flight. Lift is perpendicular to drag pointing up in the aircraft, which means it points up relative to the Earth if we are flying straight and level. W obviously points down. The only unresolved force is drag so we point our engine thrust forward to balance drag.

Airspeed and Lift

Now if we bring back our equation for lift, we see that $L = W$ gives us a direct equation for speed:

$$L = q * S * CL = W = 0.5 * \rho * V^2 * S * CL$$

solving for V^2 we get $V^2 = (2 / \rho) * (W/S) / CL$. Now if we use sea level density for ρ and then use proper conversion factors we get the useful expression

$$VI = 17.16 * \text{SQRT} ((W/S)/CL)$$

for VI in knots and W/S in lbs per square foot. Notice VI is used to show this is an indicated speed based on sea level density. That is, at any altitude, if you fly at the same CL as at another altitude, your indicated airspeed will be the same. You can turn this around and say, if you fly at the same indicated airspeed at two different altitudes, your lift coefficient will be the same. This equation says a lot but does not answer all questions you may have about speed. Max cruise speed cannot be determined. It would be infinite if you could fly with zero lift but that would be impossible of course since weight would not be balanced. It is mainly useful at low speed. Note that low speed depends more directly on having a high lift coefficient than on the drag coefficient though we will find the influence of drag shortly. The highest CL for which we have stability will determine the minimum speed. This is how stall speed is defined. If you need to guess at a reasonable clean stall speed (which is often not given today for jets), assume a max CL of 1.4 to 1.7 (generous) and use the above equation.

Thrust/Weight Ratio

If you take the two expressions $T = D$ and $W = L$ and then divide T by W and D by L (which is a legal algebraic operation assuming L is always non-zero) you get the very simple yet powerful expression:

$$T/W = D/L = (q * S * CD)/(q * S * CL) = CD/CL = 1 / (CL/CD)$$

Remember that this only holds true for steady horizontal flight and neglects the small effect of thrust alignment. (Thrust can be canted into the lift direction a little bit.). We now have a way of finding all the speeds at which an airplane can fly providing sufficient thrust is available. Any who have a spreadsheet like Excel can set up a calculation that uses the following equations which we have already discussed. We start with V_I , an indicated airspeed we'd like to fly at. We end up with T/W , the thrust weight ratio required to fly at that speed.

First, from our airspeed equation we can get CL :

$$CL = (W/S) * (17.16 / V_I)^2$$

Then, from the total drag equation:

$$CD = CD_0 + (CL^2) / (2.67 * AR)$$

Then

$$T/W = CD / CL$$

If you know the stall speed, start with that value and go up to three times that value. That is the speed at which things would start breaking under 9 g's if the wing happened to develop max lift. You will also find, however, that the T/W needed increases rapidly with speed. One problem to remember is that, to go fast, you need the true airspeed corresponding to this indicated speed at a high altitude like 45,000 ft. But, at that altitude, the pressure ratio is so low you are only getting about 15% of the rated sea level engine thrust. You will see an interesting result if you plot T/W versus V_I . There will be a minimum at max L/D which occurs at a low speed. To fly level at *slower* speeds you must *increase thrust!* That is why slow flight down the glide slope sometimes requires rather high thrust or power levels.

This is intended to show you that, while we don't know all the things that can happen in a dynamic simulation of flight, there are certain basic things we do know that can be used to show us what to expect in cruising flight.

Aerodynamic Efficiency

The ratio CL / CD or L/D is often referred to as “aerodynamic efficiency”. In its relation to T/W we see one reason for this since, at maximum L/D , a minimum amount of thrust is needed to cruise a given weight. It can also be shown that L/D is the same as the ratio of glide distance to altitude for any gliding flight problem. If you lose your single engine while at 10,000 ft (nearly 2 miles) you can glide 16 miles (without figuring wind drift) if the plane has an L/D of 8 which is typical of a trainer. If you set up a spreadsheet calculation for the set of equations listed above, you might want to make a separate column for CL / CD just to emphasize its importance. In designing an aircraft you might want to set this as a cruise condition at very high altitude.

6. ENTERING BASIC AIRCRAFT DATA

As we have just seen, basic data like wing area, aspect ratio and weight are very important in duplicating the performance of a real aircraft in FS98. You can find the proper specifications for many aircraft in a variety of sources. Try your local library. Look for the "Jane's books" - Jane's All the World's Aircraft for 19-- . There are Jane's books for every year since World War Two. There are also some special editions such as JANE'S FIGHTING AIRCRAFT OF WORLD WAR II and JANE'S ENCYCLOPEDIA OF AVIATION. The latter two books are fairly cheap (under \$40). I found them in local bookstores. The annual JANE'S books are horrendously expensive (\$285 per volume) so you want to look in a library for them. Another book called BRASSEY'S WORLD AIRCRAFT & SYSTEMS DIRECTORY is nearly as good with annual editions that sell for under \$100. These do not give quite as much info as JANE'S but cover all the basic dimensions and weights with some performance figures. A subscription to FLYING Magazine is also recommended. That magazine gives good pilot reports with full specs on a wide range of aircraft from single piston to bizjets and an occasional airliner. Save your old issues. In the past, FLYING has published Annual Buyer's Guides which are very handy because they summarize the specs of all aircraft in production during that year. The author's 1985 Flying Annual gets used continuously for weights, wing dimensions and performance. (He had two copies and left one in the office at retirement.) Maybe if we ask the editor, J Mac McClellan nicely, he'll publish another one now that several airplanes are being built again. You cannot get subscriptions to two top-quality magazines, AVIATION WEEK & SPACE TECHNOLOGY and AOPA PILOT, unless you are an aerospace professional or a licensed pilot. But, if you know anyone who subscribes, maybe you can get old issues. They are also in some libraries. AVIATION WEEK has recently published two books of pilot reports available at many bookstores. AOPA is the Airplane Owners and Pilots Association open to any licensed pilot or student pilot.

Max Takeoff and Fuel Weight

The main two weight numbers you need are the max takeoff weight (MTO) and the fuel weight. In FDE the fuel is entered in gallons for two or more tanks. To get fuel weight, multiply the total fuel gallons by either 6.0 for piston planes (aviation gasoline) or by 6.6 for jet fuel. Subtract this fuel weight from the max takeoff weight to get the dry weight with full fuel which is an input improperly labeled as “zero fuel weight” in some versions of FDE. This number is entered way down in the section on dynamics. The term “zero fuel weight” is a spec commonly given for jet aircraft that has a very different meaning. Zero fuel weight means the max dry weight a plane can carry for structure and stability reasons. But, usually it does not allow carrying full fuel. If you use the listed “zero fuel weight” and then add full fuel, you will exceed the max takeoff weight in most cases. Having the max dry weight with full fuel, you might subtract the listed empty weight to see what cabin payload the plane has. Note that for jets a Basic Operating Weight (BOW) is often given which includes a full crew and normal equipment needed for a flight. Use this instead of Empty Weight to figure payload. Airplane sellers have been playing games for years with the number of seats and the amount of useable payload and fuel. Typically, if you fill all seats, you can’t fill the tanks and you won’t get the specified max range. In FS, you can’t set payload for a given flight (nice if you could). You simply have to keep track if you simulate a flight where you trade fuel for payload. Do not consume more fuel than you would have had on board.

Wing Data

In the FS98 .air file which you can change using FDE, there are direct entries for wing area, span and chord. Make sure these entries make sense according to the relations $b*c=S$. Unfortunately there is an “input” for clean stall speed. If you need to change this, do not make an entry in the FS98 airfile using this input because it will be ignored. If you have access to the FS5 flight model, you can make the change there and re-convert the flight model to FS98 form. That is the only way. When starting an aircraft design in FS5 as modified by Flight Shop for entry of flight dynamics parameters, the wing entries are span (inches) and aspect ratio. From these entries the program calculates the wing area. Also, in FS5 you can enter values for clean stall speed and flaps stall speed. This fixes the range of CL with, and without, flaps. When converted to FS98 format, we see the clean stall speed, and, we see a Flaps Lift Coefficient which will produce the flaps stall speed in steady level flight.

CG Height and Main Gear Length

The two values of CG Height (near the top of the file) and main gear position below CG must agree. Unfortunately for some reason the value for CG Height is given in strange units. If these values don't agree, the plane may fall and crash every time you try to load it. There is also a parameter called fuselage angle. This may be important for tail-wheel aircraft. It is difficult to use tail-wheel aircraft because you can't turn a tail-wheel aircraft on the ground in FS98. For normal aircraft just set the Fuselage Angle to zero. The CG Height must be calculated by the following formula:

CG Height = 1665 * (-MGZ) where MGZ is the "Main Gear Position above +/-

below the C of G". MGZ will always be a negative number in inches. Make it a positive number and multiply by 1665 to get the CG Height which is actually called: C of G above ground. When you do this and you select the aircraft from the FS98 menu, it is placed above the ground, held level and at a height where the main gear just touch the surface. It is then released and allowed to fall onto the gear which, if properly designed, will compress a little allowing the aircraft to settle at an appropriate attitude. It may rock a bit initially, when you start the engines and when you taxi. That's okay - real airplanes do that. There may be special aircraft with short nose gear where you need to calculate a fuselage angle other than zero.

The Center of Gravity or C of G

This is as good a time as any to try to prepare those of you who are pilots and engineers for this weird concept the designers of Flight Shop and the Microsoft Flight Simulator had of using the center of gravity as a primary reference position for locating all points on the aircraft like the wheels (ie- "gear"). Certainly in dynamics, the CG is a very important point. But, in aircraft it cannot ever be used as a standard reference because it changes between various missions and even during a mission as fuel burns off (or as things are dropped). The designers should have picked an arbitrary reference point as the origin of coordinates and then specified the position of all parts, including the CG, from this origin. Why they didn't realize this is an indication this program was designed by software engineers. Maybe someday they'll wake up. For the time being, we must put up with this notion that the CG is the origin of coordinates. If we were to move the CG according to payload position (a common practical situation), we would have to change every coordinate of every component on the aircraft!!!

The main CG entry to set in FS98 with FDEditor is the position of the wing center of lift ahead (+) of or behind (-) the CG. A value of zero is OK but any small negative value (a few inches) is better for stability.

Limiting Speeds

Aircraft have limiting speeds beyond which they cannot be flown safely. For piston aircraft, there is VNE or never-exceed speed. This is an indicated airspeed which is normally 3 times the clean air stall speed. The input for VNE in FDEditor is labeled VMO which is the equivalent parameter for jets. Jets also have a limiting Mach number labeled MMO. While the VNE and VMO limits are based on structural limitations, MMO is based on stability and control considerations. As the Mach number gets closer to unity, the center of pressure of the aerodynamic loads shifts dramatically. Most subsonic aircraft have control limits that are inadequate to maintain control above some Mach number. MMO is well below that value. Curiously, the FS programmers setup VMO in default in the conversion program as the true airspeed equal to MMO at sea level. It should be a much lower indicated airspeed value equal to 3 times the clean stall speed. It is the speed at which a sudden excursion to max lift coefficient would generate 9 g's of lift. For some reason, MMO is near the top of the data list and VMO is near the middle where the clean stall speed and dry weight are located. FS98 will sound an overspeed alarm if either MMO or VMO are exceeded.

7. ENGINE POWER AND THRUST

Setting power for piston engines

The specification for piston engines is given as power - horsepower. From the equations of motion we know that piston engines must develop thrust in order to fly. However, the amount of thrust developed is a complicated function of the engine and propeller characteristics. Each engine has a power rating given in horsepower or "hp". This is the main entry you can make for a piston engine, maximum power. Most piston aircraft have a "constant speed" prop. This is a prop you can control with the "Prop" lever setting the RPM you want to fly. The throttle then sets the manifold pressure or mp measured in inches (of mercury like barometric pressure to which mp is related). When flying, you set the engine power level by setting both RPM and mp. Here is a table that holds for most modern piston engines:

75% Power = 2400 RPM and 24 inches mp (normal cruise)

65% Power = 2300 RPM and 23 inches mp (quieter, economical)

Low Power for Descent = 2100 RPM and 15 inches mp

For decades, pilots have flown piston aircraft without a clear indication of the power they are setting. Today, we finally have some panel-mounted computers that show exact power settings based on engine control settings and flight conditions.

Prop Diameter

Prop diameter is an important entry. Although there is some question as to whether 3-blade and 4-blade props are correctly handled in FS, we can assume they are and can enter the actual prop diameter in inches. However, if acceleration on takeoff or climb rate are poor, consider increasing the prop diameter slightly. This needs adjustment also with some large engines having 130" to 190" props. Sometimes a smaller diameter works better. The prop diameter will change the effective power if very large or very small. Using the value in published specs for the aircraft seems to work well.

EGT Scalar

Another parameter to adjust is the EGT Scalar. EGT is the exhaust gas temperature. This scalar sets the sensitivity of the EGT gauge. This is a very important gauge because it allows the plane to reach full cruise speed for a given power setting and altitude. When the plane is level at the cruise altitude, adjust the mixture control while watching the EGT gauge taking care to wait for the needle to respond fully before changing the mixture. First you move the needle to a peak position (max temp); then, you back off toward the rich side one or two notches. Without doing this properly, your cruise speed will be low by several knots. Set the scalar so the needle gives nearly full deflection at peak at about 8000 ft altitude. This will make it easy to find peak at most altitudes.

Equations in FS98 for the variation of power with altitude are reasonable but not quite right because they produce essentially a constant true airspeed at 2400 RPM regardless of altitude from 2000 ft to 10000 ft. This is not realistic. There should be a maximum true airspeed at some median altitude around 6000 ft to 8000 ft. Usually, drag would be set to get the specified cruise true airspeed at the specified altitude. This often results in a better cruise speed at other altitudes than would actually be found. The difference, however, is only a few knots. A major shortcoming of FS98 is that it does not model the performance of turbocharged piston engines which can maintain their sea level power to a medium altitude and still produce sufficient power above 20,000 ft to achieve the indicated airspeed associated with normal cruise. The high true airspeed is the speed listed in specs though it may take 40 minutes to climb to that altitude. The author has modelled some but only providing proper performance up to 9,000 ft which is typically where the difference with turbocharging begins to show. Thus we cannot model some very good and popular aircraft in a realistic sense. Above 12,000 ft, people require continuous oxygen supply from tanks if the aircraft is unpressurized. Therefore, most such aircraft are probably flown below 12,000 ft most of the time anyway. People don't like wearing oxygen masks for a long time.

Setting Thrust for Jet Engines

Turbojet and fanjet engine specifications give max sea level thrust which is the main input for jet engines. There are no other normal inputs you need to make. The equations in FS98 calculate the thrust available at altitude quite accurately. When flying, set the climb thrust at 100% and then set whatever is required to cruise at the prescribed Mach number. Fuel flow from a cruise test can be used as the indication of proper thrust when cruising at low altitude. Speed will be low but that's better than burning fuel at a high rate or over-working the engine.

Setting Thrust for Propjets

In FS98, it is important to treat “propjets” as the jets they really are because this allows them to have proper performance with altitude. The problem for us is that turboprop engine specs give only shaft horsepower, not thrust. We can solve this little problem by dividing weight by a low L/D such as 4 and dividing the result by the number of engines. This gives a number that will usually suffice to begin flight tests. There is normally a climb rate spec and often a best climb airspeed spec. These can be used to fine-tune the thrust level set for the engine in the .air file. There is normally a cruise fuel flow rate spec which is used to set the fuel flow parameter as described below. Use the flow rate to set the engine when flying at various altitudes. Below are some thrust settings from aircraft in the author’s “hangar”. This should give you a guide.

AIRCRAFT	MTOW	THRUST/ENG	T/W
Piper Meridian	4835 lb	1353 lb	0.280 (1 eng)
Beech C90SE	10101 lb	1121 lb	0.222 (2 eng)
Beech B200	12428 lb	1394 lb	0.224
Commander 1000	11192 lb	1399 lb	0.250
Fairchild 300	13218 lb	1652 lb	0.250
Metro III	14556 lb	1722 lb	0.237
C-130	135857 lb	8501 lb	0.250 (4 eng)

Fuel Consumption

Several years ago with FS95, the author identified a parameter in each of the piston and jet engine sections that seemed to affect fuel consumption. It is noted in FDE as “Fuel Consumption Factor”. For piston aircraft it has a default value of 138 and for jets a default value of 400. For piston aircraft, 138 usually gives too much fuel consumption so reducing this value 5 to 10 points gives more accurate consumption. You have to try different values, testing them by measurement of fuel used over 10 to 15 minutes. However, beware that increasing the value beyond 138 is not good as it has a peculiar effect on power. Most jets by default have a fuel flow rate much lower than reality. In FS5, there was a direct parameter called TSFC which is a real parameter given in engine specs that we can relate to (pounds fuel per pound thrust). It was easy to set this correctly based on information published by engine manufacturers and to see proper fuel flows as a result. In FS95 that value was carried through the converter but the measured fuel flow was very different. The parameter labeled “Fuel Consumption Parameter” with a range of 390 to 460 does indeed affect indicated fuel flow on the panel gauge. This is a handy indicator of proper thrust setting when cruising at lower altitudes than usual for a short distance. Fuel flow in pounds per hour per engine is also a

common spec for cruise power settings in publications. Hence this parameter has been used to adjust fuel flow at cruise to match the spec.

However, recent tests have shown that the actual fuel consumption can differ from the indicated value by as much as 7 percent. Measurement is by noting the different fuel readings over several minutes (usually 15 minutes) and calculating pounds per hour. Even looking at the fuel values is tricky and confusing. There is a digital display of fuel remaining shown on the panel. This never agrees with the values given by selecting Aircraft Settings/Fuel on the Aircraft menu. The value you see when first looking at that Aircraft Settings/Fuel will change by 10 to 50 lbs if you simply close the window and re-open it with the aircraft paused. What is the real value?

Estimating Range

The author has developed the following method for estimating the range of any aircraft with a flight test. Set the wind to zero at all altitudes. Takeoff and then, during the initial climb (above 400 ft AGL) turn to a course 90 degrees from the runway heading. (This is an average change of heading.) Climb using the autopilot in HDG and ALT modes while adjusting the climb rate to maintain a good trade between airspeed and climb rate. Jot down data at periodic intervals during the climb: altitude, time, distance (GPS), KIAS, fpm, and fuel remaining. At the normal “best cruise” altitude, level off and let the speed build to the normal cruise speed. Then set normal cruise power (lean properly if using a piston engine) and set proper cruise fuel flow (indicated) if in a jet. Note the time, distance, KIAS, KTAS, fuel remaining, indicated fuel flow and Mach. Let the plane continue for 15 minutes. Then note the same data. Calculate the actual fuel flow from the difference in fuel remaining at the two times and multiply by 60/15 (or whatever number of minutes actually elapsed). In some jets, you may want to continue the test climbing to another altitude or accelerating to higher Mach number. When the cruise-start data sets have been recorded, turn back toward the airport and do the descent portion of the test. Start the descent at a distance about 3X the altitude divided by 1000 (eg- at 120 nm for an altitude of 40,000 ft). Before starting the descent, reduce the fuel on board to about 20% to get the weight realistic. Also, note the distance and the fuel remaining. Fly a normal descent and approach to a landing. Park the aircraft appropriately. Note the amount of fuel remaining.

The estimated range, for a particular cruise condition, consists of the distance during climb, the distance during cruise and the distance during descent. To determine the distance during cruise, take the fuel remaining after the climb and subtract 75% of one hour’s fuel (75% of the fuel flow) and subtract the amount used during the descent. Call the remainder the “enroute fuel”. To find the enroute distance, first divide the cruise fuel flow by the true airspeed to get a flow amount per nautical mile or “mileage”. Then divide the enroute fuel by this mileage and the

result is the enroute distance. Add the enroute distance to the climb distance and the descent distance and you have the standard “range with 45 minutes reserve”. You might want to re-work the data using different amounts of fuel subtracted from the amount remaining after climb to get the effect of leaving some fuel home in exchange for passengers. The takeoff weight would be the same but less fuel would remain for cruise. Most published range data specifies the number of passengers on board (in very fine print). Listed below are range values estimated for the four Learjets on my web site. These are close to, but not exactly equal to, the published values given for these aircraft (BRASSEY’S WORLD AIRCRAFT & SYSTEMS DIRECTORY, 1997).

Estimated Learjet Ranges

(All cases include 2 crew + 4 pax and 45 minute reserve.)

AIRCRAFT	DRY WT	PUBLISHED	ESTIMATED
Learjet 31A	11940 lb	1561 nm	1649 nm
Learjet 35A	11319	2196	2158
Learjet 45	14350	1932*	1987
Learjet 60	15440	2750	2697 (M.71) 2541 (M.75)

*Source: www.learjet.com/0_0en.htm 10/27/99 BOW has changed recently.

The effective range for any trip is the actual range multiplied by a factor to compensate for wind. No matter how fast the plane flies, there is always a wind that can make a long trip longer. Jets fly fast but see headwinds often as high as 150 knots or 1/3 their cruise speed. The correction factor is simply $V/(V-W)$ where V is the true airspeed and W is the speed of a headwind (use a negative number for a tailwind). This can also be expressed as $1/(1-W/V)$ so in the case where the headwind is 1/3 the cruise speed, the trip distance will be 1.5 times as long as the actual distance. The pilot must be sure his range is greater than the effective distance. A more common case with all aircraft is a headwind of 1/5 the cruise speed making the distance 25% longer. If you fly a Cessna 172 at 100 knots at 4000 ft, you’ll find a 20knot headwind waiting for you either coming or going. (No, it doesn’t quite average out. Wind causes a delay in the total time coming and going.) If you fly a turboprop at 250 knots at 20000 ft, a 50 knot wind is waiting to cause an extra fuel stop!

8. MOMENTS OF INERTIA

Why MOI? There is a basic relation for rotational acceleration that is similar to Newton's Law for straight-line acceleration. The torque required equals the product of the moment of inertia and the rotational acceleration in certain very simple cases. Actually, in a sim we turn this around and solve for the rotational acceleration as a function of several terms, the first being the torque applied divided by the moment of inertia for the axis we are concerned with. There are other terms involving existing rotational velocity components, but, we needn't get involved in all that now. Consider this anecdote. As a kid, the author had a large afternoon paper route of over a hundred papers that could only be serviced by folding all papers ready for throwing and then riding his bike quickly down a street throwing the papers at the base of each front door. He found a strange phenomenon. It is impossible to flip a properly folded paper up lightly in the air and have it rotate only about one axis and return to your hand. Take a symmetrical object like a paperback book and you can do that easily. Suppose we say we are flipping the book or paper about its pitch axis. You can flip the book a half turn so it lands with the opposite face up. No matter how hard you try to flip the paper like that, it will come down with the same orientation it had before the flip. It is rolling while it is flipping. It took over fifteen years for this kid to learn that the mass distribution caused by the folding process was responsible for that little mystery.

Probably the most esoteric aspect of setting up an aircraft model for FS98 is the estimation of Moments of Inertia or MOI's. You need to enter an MOI for roll, pitch and yaw referenced to the three standard aircraft axes. In theory, these are calculated by summing the product of the mass of each component with the square of its position radius about the axis. This is a very daunting task. Yet the MOI's play a very important part in the flight characteristics of the aircraft. The roll MOI determines how much the aircraft resists the roll control input, for example. Also, the relative values for the different pairs of axes determine the coupling between axes. A simple roll input will typically produce secondary yaw and pitch rotations as well as a roll rotation. The direction of rotations is determined by the difference between the pairs of MOI's: $(I_x - I_y)$, $(I_z - I_x)$, $(I_y - I_z)$. Hence, to model a plane's behavior well, it is important to nail down these MOI's with reasonable accuracy. It is helpful to think a little bit about how the relative size of the MOI's is determined. To find the pitch MOI, we look at the position of masses relative to an axis passing through the wing. Thus the wing itself and any engines mounted on the wing do not contribute much to the MOI. Any heavy weight in the nose or tail would contribute significantly. To find the roll MOI, we look at the position of masses relative to an axis passing through the center of the

fuselage. Here the wing and any engines mounted on the wing make big contributions but anything in the fuselage does not. Modern jets with engines mounted near the fuselage have a low roll MOI. To find the yaw MOI, we look at the position of masses relative to a vertical axis through the wing/fuselage joint (centered on the fuselage). Almost everything on the aircraft that is offset from the CG contributes strongly to this. Therefore we would expect the yaw MOI to be the largest.

Dr Jan Roskam, has published an 8-volume set of texts on aircraft design. He has taught courses in aircraft design for some time at the University of Kansas and has developed a method for estimating MOI's that uses only basic aircraft weight and dimensions combined with a set of coefficients of radii of gyration for several specific aircraft. We simply determine which aircraft is similar to the design we are concerned with, take the coefficients for each axis and the appropriate dimension and calculate MOI's. The formulae are:

$$I_x = (W/g) * (R_x * b/2)^2$$

$$I_y = (W/g) * (R_y * d/2)^2$$

$$I_z = (W/g) * (R_z * e/2)^2$$

where $g=32.2$ (gravity acceleration)

W =max takeoff weight (MTOW, lb)

b =span (feet)

d =length (feet)

$e=(b+d)/2$

and R_x , R_y and R_z are chosen from the table for the aircraft type. Some of Dr Roskam's dimensionless radii of gyration for several aircraft are given below (used by permission). All are set at full fuel and MTOW.

AIRCRAFT	ROLL Rx	PITCH Ry	YAW Rz
Low Wing Single (Beech N-35)	.248	.338	.393
High Wing Single (Cessna 182RG)	.242	.397	.393
Light Twin (Beech 55)	.260	.329	.399
Medium Twin (Cessna 402)	.373	.269	.461
Light Jet (Cessna 550 (Cit II))	.293	.312	.420
Medium Jet (Lockheed Jetstar)	.370	.356	.503
Twin Turbo Prop (Fairchild F-27)	.235	.363	.416
Four Eng T Prop (Electra)	.394	.341	.497
Jet Airliner 4 eng (Convair 880)	.322	.339	.464
Jet Airliner 3 aft eng (B 727-200)	.248	.394	.502
Jet Airliner 2 eng wing (B737-200)	.246	.382	.456
Jet Airliner 2 aft eng (DC-9-10)	.242	.360	.435
Prop Airliner 4 eng (DC-6)	.322	.324	.456
Prop Airliner 2 eng (Conv 340)	.308	.345	.497
Jet Fighter (F-86)	.266	.346	.400
Jet Fighter (F-104)	.224	.392	.563
Jet Fighter (F-102)	.295	.386	.520
Prop Fighter 1 eng (F4U Corsair)	.268	.360	.420
Prop Fighter 1 eng (P47)	.296	.322	.428
Prop Fighter 2 eng (Bristol Beaufrt)	.330	.299	.447
Prop Bomber 4 eng (B-29)	.316	.320	.376
Prop Bomber 2 eng (Martin B-26)	.270	.320	.410
Jet Bomber 4 eng (B-47)	.346	.320	.474
Jet Bomber 8 eng (B-52)	.346	.306	.466
Flying Wing (RB-49A)	.316	.316	.510

These data were taken from **Airplane Design Part V** by Jan Roskam. ISBN 1-884885-50-0 published by DARcorporation, Lawrence, Kansas, used by permission.

The author started using this method with Flight Shop for FS5.1 because he noticed that the estimation method used within Flight Shop was way off making many aircraft behave strangely. The values they suggested did not vary with aircraft weight and basic dimensions as they should. Also, for a while with FS95 and FS98, there was a bad problem with landing dynamics that many developers “solved” by increasing the MOI’s. However, the landing gear inputs in FDEditor fix the landing gear appropriately making it possible once again to use correct MOI’s for a considerable improvement in handling realism.

9. LANDING GEAR DESIGN

Proper landing gear design is one of the most important things you can do using FDE. Almost all aircraft converted from earlier versions of FS have poor landing dynamics in FS98 because the conversion process does not properly set the landing gear parameters for spring constant and damping coefficient. Evidently the FS designers made a significant change in the gear simulation and forgot to tell the aircraft designers. Even the original aircraft supplied with FS98 land poorly on stiff gear. This makes them bounce a lot. Curiously, the problem becomes worse the smoother the landing. Since all new designs must first be set up in the earlier version, FS5.1, and then converted to FS98, this is a big problem. For example, the XAS jet bounced so badly just taxiing, it could not be loaded without a crash. It could start parked with the engine off and it would rock fore and aft a little, then a lot and finally jump up and crash on its tail or nose!

Parameters

In FDEditor, someone identified two parameters, spring loading and damping, for the main gear and for the center gear. These parameters had been mis-identified in other editors. Shortly after seeing this listing of parameters, the author was able to fix all his hopping problems. Though the mains only carry part of the static load, and during landing the wings are still contributing significant lift, the main gear springs are sized on the assumption they support the whole aircraft in a dynamic condition at landing. If they supported the entire aircraft in a static load, the force would be W , the total landing weight of the aircraft. But in a dynamic condition, we assume the springs are fully stretched and unloaded when the wheels touch. Then the aircraft falls onto the springs which compresses them until their force has stopped the fall. In this motion problem the potential energy of the fall is $W*z$ and the energy absorbed by the spring is $0.5*k*z^2$ where z is the total compression. Potential energy passing into the vehicle equals energy absorbed:

$$W*z = 0.5 * k * z^2 \quad (\text{k is the spring constant})$$

Define z_1 where $k * z_1 = W$, the static load deflection. Then we find

$2*W = W * z / z_1$ and $2 * z_1 = z$. This means the dynamic load is twice the static load or $2*W$ since the deflection is twice the static deflection when the potential energy is absorbed. We can play safe, allowing for a little extra kinetic energy by increasing the "spring loading" a little beyond twice the weight.

Stopping Hopping

Here's the solution: First, figure the total weight by adding the fuel weight to the dry weight as found in the .air file. We'll call that W . Then calculate and enter the following values in the Landing Gear Section of FDE:

Main Gear Spring Loading Factor = $2.72 * W$

Main Gear Damping Factor = $0.34 * W$

Center Gear Spring Loading Factor = $2.04 * W$

Center Gear Damping Factor = $0.24 * W$

You may want to adjust these values after trying some landings. However, these settings will be good enough for safe landings. These exact values were taken from the author's Aerospatale Trinidad. Factors from a heavier jet are: 2.01, 0.34, 0.86 and 0.11 which are the values for the 35,000 lb Galaxy jet. You have to watch for excessive compression or excessive stiffness. With excessive stiffness you will hear a series of strong chirps as the wheels barely touch the runway on a smooth landing. In bad cases the plane will bounce fore and aft or left and right (in roll) as the wheels chatter on the runway. With these good values, any landing with touchdown velocity between 0 and -400 fpm will look and sound smooth.

10. SETTING AERODYNAMIC COEFFICIENTS

The main dynamics section of data in FDEditor allows you to insert aerodynamic force and moment coefficients to set the flight characteristics in a basic sense. We will first list typical values so you know the range of numbers to expect, and will then discuss how to adjust them according to flight conditions.

PARAMETER	VALUES
Zero Lift Drag	0.016 to 0.036
Gear Drag	0.03 to 0.05
Flap Drag	0.06 to 0.10
Flap Lift	0.3 to 0.9
Spoiler Drag	0.05 to 0.07
Spoiler Lift	-0.05 to -0.25
Pitching Moment, Gear	0.02 to 0.04 **
Pitching Moment, Flap	0.03 to 0.05
Pitching Moment, Spoiler	0 to 0.015

** In FS98, a positive pitching moment is nose down.

Effect of Parameters on Flight

Zero Lift Drag coefficient affects both the climb rate for a given power setting at a given altitude and the cruise speed. During climb, the induced drag is of some influence so the purest effect of zero lift drag coefficient is at cruise. We can set this value to achieve a precise cruise speed as specified at a particular altitude and power setting. In the case of turboprop jets, the thrust at cruise cannot be specified. In this case adjust thrust level to get a specified climb rate at 100% thrust and then adjust zero lift drag for cruise speed. Fuel Flow is also an important adjustment for turboprops because that is the practical way of setting cruise power at non-specified altitudes. Zero Lift Drag has very little effect on slow flight which is dominated by the drag induced by lift. Aspect ratio is significant for slow flight. Aircraft with high aspect ratio wings are more difficult to slow down. Gear Drag is useful but there is always a limiting airspeed above which the gear cannot be lowered.

Gear Drag coefficient depends on the relative size of the gear. This value should only be set for aircraft with retractable gear. For aircraft with fixed gear, this drag is incorporated into the Zero Lift Drag. A value of 0.03 is good for clean and simple gear. For complex gear with multiple wheels per bogey, use 0.05 or even 0.06. While flying, this value will cause a slight to moderate deceleration when the gear are deployed. On a normal ILS where the glide slope is intercepted at about 2000 ft AGL, you would fly level with gear up to the glide slope and then drop the gear to begin descent. This generally occurs at the outer marker which is a good

time to check for gear down. There is usually a slight nose-down pitching moment as the gear deploys.

Flaps Drag and Lift coefficients are really deltas or changes in the coefficients. The full effect is not seen until the flaps are fully deflected. While many people think flaps mainly create drag, the increased lift coefficient is what enables a plane to fly slowly. The amount of the flap lift should be calculated using the equation below:

$$CLF = 294.5 * (W/S) * (1/VF^2 - 1/VC^2)$$

Note that the last factor is one divided by the flap stall speed squared minus one divided by the clean stall speed squared. VF is the flaps stall speed and VC is the clean stall speed . W/S is in psf (or lbs per square foot) and the speeds are in knots indicated. You may want to find VC by flight testing before performing this calculation.

To do a stall speed test, set the aircraft in steady level flight on autopilot, slow down, drop gear but maintain enough power so the speed decreases slowly. Watch the vertical speed. As soon as the vertical speed drops from zero, mark the airspeed as the stall speed. This test can be performed at any medium altitude (5000 to 8000 ft AGL).

Flap pitching moment is usually slightly nose down (positive in FS98). Many pilots will set a strong nose-up moment because they see the nose tending to come up when flaps are deployed. This is a response to the added lift tilting the flight path upward, not to the pitching moment. When first deploying the flaps, you push forward to reduce the flight-path pitch up and then relax the pressure as the speed decays. Then you may need to trim some nose up to compensate for the flaps pitching moment.

Spoiler Drag is usually only a little more than gear drag. Sometimes it is less. Like flaps, many people think the spoilers main job is to increase drag when it really is to decrease lift. They “spoil” the lift on a portion of the wing. This is particularly helpful in keeping an aircraft on the runway after landing. There are inputs for Spoiler Lift and Pitching Moment. With any aircraft having spoilers, arm the spoilers at the same time you drop the gear so they will deploy automatically on landing. (Note there is a line in FDEditor to enable spoilers and another line farther down to enable Autospoilers. Make sure these are “Yes” for all jets). (Note many turboprops do not have spoilers.) To set the levels of spoiler drag, lift and pitching moment during flight tests, set up a normal descent from about 30,000 ft at 2000 fpm and then deploy spoilers. The descent rate should go to about 3000 fpm but the airspeed should decrease a little. For landing, a slight nose-down moment (positive) is helpful.

11. CONTROL SENSITIVITY

One of the most common complaints about FS airplanes heard on the forums is that the planes are too sensitive to control. Unfortunately, all too often the complainer sets his joystick sensitivities at the max level and then can be seen jerking his stick around. Hence, before we get into roll, pitch and yaw stability and response, we should discuss joystick set up and how to use the controls.

There is one thing to keep in mind and that is your mind. Your brain is the essential control interface. You should have a good idea of the response you expect and then you will easily manipulate the hardware in any fashion needed to produce the effect. Your fingers should be busy tapping the trim keys any time you make a transition from one phase of flight to another. The stick initiates the takeoff rotation and the landing flare. After the takeoff rotation, and after raising the gear and retracting the flaps, trim out the stick force for a climb at the best climb airspeed (which should be given in the checklist). The only time you hold the stick against a little force for a while is during the flare.

Joystick Sensitivity

Under Options/Custom Controls you can calibrate your joystick (make sure joystick is selected ON in the upper left corner) and you can set the sensitivities for each axis and for the rudder control. Make sure you have selected your joystick instead of the keyboard or mouse. The author sets his sensitivities low. For the roll axis, set null on the first mark right of zero and the sensitivity on mark #3. For pitch set null at 1 and sensitivity at 2.5. For the rudder pedals set null at 1 and sensitivity at 4. No throttle control on the joystick or yoke can be recommended because all hardware appears so poorly made you can't adjust power as accurately as with the keyboard. The same goes for trim on the stick or yoke. The keyboard may seem like a strange way to set power but you can bump the key for small incremental changes while looking at flow rate and get just the right setting which is critical for jets.

Force-feedback sticks cannot be recommended for two reasons. One reason is you should learn to trim out forces as you fly for any type of flying except aerobatic. This works fine with a spring-centered analog stick which is strongly recommended. Any force-feedback would be wasted except maybe in roll which is typically a mild input in most flying. The second reason force-feedback sticks cannot be recommended is that no guidance whatever has been given to those of us designing aircraft for FS on how to adjust the force-feedback parameters. Therefore they are all the same for all aircraft! That can't be realistic.

What do we mean by “trimming out the force?” Before starting takeoff, set the pitch trim properly for takeoff. All the author’s aircraft are furnished with flying instructions and a Flight Situation that shows the aircraft properly set for takeoff including trim. Also, he has been adding checklists for many of the aircraft that describe how to set takeoff trim. With trim properly set, the aircraft needs just a nudge to rotate and fly away with back pressure reduced once climb speed is gained. Trim the nose down until you reach the recommended climb speed. Once you reach 1500 to 2000 ft AGL, level off and add nose-down trim gradually as speed increases maintaining low stick forces. Once at cruise speed with cruise power set and mixture leaned, trim should allow you to remove your hand from the stick with the aircraft remaining in perfect level flight. The same thing would occur if you turned on the autopilot setting the heading hold and altitude hold functions (normal operation). Note after the autopilot trims the aircraft, you can turn off the autopilot and the aircraft will continue in straight and level flight unless disturbed by turbulence. When cruise-climbing to altitude or descending from altitude, the aircraft should be in perfect trim with no pitch stick force. A little stick work is needed to level off but after power is adjusted no further effort should be required. Typically in a piston aircraft, 15 inches manifold pressure and 2100 rpm are used during descent from cruise altitude and the same setting when level in the vicinity of the airport allows slow enough speeds to drop gear and then drop flaps. Power increase will be needed after flaps and gear to maintain level flight. Trim adjustment is needed after these events but power reduction will start the aircraft down the glide slope. The stick isn’t very busy in pitch. At the flare a slight backpressure holds the nose off until the mains touch. There is never a need to jerk the stick to full deflection in normal flight.

Roll Rate and Roll Stability

When an aircraft has been originally developed for the simulator with large MOI values, such as the default values, if you enter correct MOI’s using Roskam’s Method, the aircraft response will improve but you may have to adjust some control parameters, particularly roll rate. In most cases this is very easy: just reduce the magnitude of the Aileron Control Factor or ACF. This is a negative number that is usually between -100 and -500. To reduce roll rate you actually increase it to a smaller negative number. (Why negative? Don’t ask.) It is much easier to control aerobatics in the Extra 300 by reducing the ACF to -500 from -1000. You can still roll 360 in about one second but you can stop when you want to.

Another problem that occurs sometimes is a roll flutter. This is a very weird condition where the aircraft shakes back and forth 30 degrees or more about its roll axis. For the Beech Duke, reducing the Roll Stability Factor 1 from -9000 to -3000 stopped this flutter. The plane has behaved well in all other modes.

The Roll Stability Factor 1, the Roll Damping Factor and the Rudder Effect on Roll are all adjustments that should be made carefully in cases where a roll stability problem exists. In many aircraft with wing dihedral, there is a significant amount of roll with pure rudder deflection. Sometimes you may want to reduce this so you don't increase the bank too much in turns. You can easily make things much worse so always be ready to retreat to the original values. Always write down the original value before changing it. FDEditor always makes 3 levels of backups for your original .air file but sometimes in the heat of making changes, you can wipe out the original. A good technique is to use a similar aircraft that flies well for comparison when making these changes.

Pitch Stability

In normal flight you are never going to need an abrupt pitch change unless you blunder into a near-stall situation. If you fly with trim adjustment after each transition between flight modes (climb to cruise, etc), you will never need a strong pitch input. Hence most of the pitch adjustments in FDE are not needed. They include Pitch Damper, Elevator Control Factor (Max Force) and Trim Pitch Factor. The Trim Pitch Factor adjusts the sensitivity of the pitch trim control. On rare occasions this may need changing if trim is overly sensitive. (We will discuss Pitch Stability Factor 2 later under Dynamics). Any aircraft is going to have some pitch oscillation in flight. It is important to understand the difference between a stability problem which is a response to unbalanced moments and the phugoid motion which is a response to unbalanced forces. Pitching motion of an aircraft is divided into two types - short period and long period motion. The latter is called "phugoid" motion. The short period motion is the only one related to pitch stability. It is controlled by the tail and causes rotation of the aircraft until an angle of attack is reached at which the moments balance. This motion occurs so rapidly we seldom are aware of it. When you rotate for takeoff, that is short period motion. There is usually little oscillation. The aircraft rotates as you begin moving the stick and stops at its new stable angle of attack as you stop moving the stick. What usually follows that rotation is the phugoid mode where, with the new angle of attack held very constant the plane rotates to follow the new flight path during which the forces may be a little out of balance. At first there is excess lift so the path is pulled up away from the runway but the speed declines a little. Then that force decays and weight brings the aircraft back down a little so the speed increases. You can damp this motion easily with very slight stick motions. It requires little attention though inexperienced students can be seen fighting with the phugoid during the first 200-300 feet of climb. You will see a little phugoid after transition from each mode of flight. When you level off after climbing to cruise altitude, it takes a long time to get the aircraft steady at cruise speed. The trim must be adjusted continuously as the speed increases. If this is not done well a slight phugoid oscillation develops.

In the equations for this simulation, the pitch damper sometimes reduces the phugoid when adjusted. That is not a good thing to do. The phugoid is a natural phenomenon and should be controlled by good pilot technique. Cleaner aircraft with a high L/D have less phugoid damping than draggy aircraft. If the wing loading is correct and the drag coefficients are correctly set, the phugoid should not be a problem that cannot be managed by proper pilot technique.

Yaw Stability

Yaw or Directional Stability is a problem with some aircraft after fixing the MOI's. It appears the best solution is to return to the FS5 model and stiffen the Yaw Stability Scalar. This seems to alter several of the yaw-related parameters in the FS98 .air file. If you don't have access to the FS5 model, it will be tough to solve these problems. You'll see a yaw problem as you try to line up with the runway, if the plane drifts sideways badly (with no wind) or oscillates in yaw in response to aileron and rudder inputs. In some bad cases it may be impossible to assure alignment with the runway though the flight path is straight toward the runway. The plane would oscillate in yaw as it was touching down. You can increase the Rudder Control Factor or the Yaw Stability Factor 1, but, sometimes these make things worse. The author has never found use for the Yaw Slide Factor, Yaw Center, Yaw Stab Factor 3 or Lateral Inertia although these may be re-set by returning to FS5 and adjusting the yaw stability scalar. These are all very non-standard aeronautical terms invented by software engineers to solve problems they could not handle in a conventional sense.

The normal setup in the flight dynamics inputs to FS5 after an aircraft is designed in Flight Shop include values for Pitch, Roll and Yaw Stability Scalars of 2, 2 and 7, respectively, providing adequate directional stability and stiffness in yaw. (The roll or pitch scalars could be increased to 3 for particularly stiff aircraft). A few designs came through with 1's for all scalars which results in a very loose aircraft that responds wildly to any control input. It is not clear how to fix this at the FS98 level. A quick trip back to FS5 always fixes the problem.

There are conventional aeronautical engineering terms that could be applied to this program - side force coefficient, roll moment coefficient, yaw moment coefficient and various damping derivatives. For some reason the authors of FS chose to invent their own terms to patch up program performance. It would help immensely if they would give us their definitions of terms and an indication of certain non-standard calculations.

12. ADJUSTING DYNAMIC STABILITY

There is a good reason this is last. It is the scariest subject for everyone. Hopefully, any problems you have with a design will be solved by the methods described above. But, we will treat the dynamic stability problems as directly as possible. You may have heard the terms “static stability and dynamic stability”. Static stability exists if there is a tendency to return to steady flight after any disturbance. Dynamic stability involves the way in which the aircraft returns to steady flight after any disturbance. Good dynamic stability “converges”. That is, there may be oscillations about the equilibrium condition but each oscillation gets smaller until finally there is no oscillation. Poor or bad dynamic stability “diverges” with each oscillation getting worse. In some cases of poor dynamic stability you can manually control the aircraft to damp oscillations and return to steady flight. An example would be a phugoid pitch oscillation with high power settings in some aircraft where, if no manual control is exerted, the motion can diverge to a loop. However, with just a little manual control, the loop is avoided and good steady flight can be attained fairly easily. You might encounter this during climb in a jet when you spend time setting up navigation equipment before turning on the autopilot. Bad dynamic stability is where the aircraft oscillates, usually in pitch until all control is lost or until an exceptionally large positive or negative angle of attack tears the wings off.

The FS Autopilot

Most of the dynamic stability problems in FS come when operating under control of the autopilot. The autopilot uses spring-type control inputs to fly the aircraft very smoothly. It does a great job of straight and level flying under most conditions as it continuously adjusts the trim until the aircraft is steady. What is meant by “spring-type” control inputs is the inputs are in direct proportion to the deflection from nominal like the force in a spring. “Deflection from nominal” could mean a velocity or an angle sensed by the autopilot which, in actuality, contains gyros on two or three axes. The autopilot in FS imitates a three-axis autopilot. It looks at the angular accelerations that gyros would see as well as airspeed, altitude and directional gyro heading to fly the plane. The problem we face is that an autopilot normally has several parameters that need adjustment for each aircraft. We don’t have access to parameters identified as autopilot parameters. Some parameters such as Pitch Stability Factor 2, discussed below, seem to affect both autopilot flight and manual flight. The same is true of roll damping and the aileron control factor.

All types of stability problems become worse with altitude. While we can fly at constant dynamic pressure if we want to, and think we are safe in doing so, the actual response rates become higher in lower density. This can cause pitch

divergence and “dutch roll” where a roll-yaw coupling can occur. This tendency toward stability problems at high altitude is a real-world problem, not just a problem in the Flight Simulator. Most real jets that fly above 40,000 ft must incorporate some form of artificial stability augmentation. This means usually turning on the autopilot and/or yaw damper whenever the aircraft is above 30,000 ft. During certification tests mandated by the FAA, these requirements are investigated and then may be issued as formally required operating procedures. Many jets cannot even takeoff legally if the autopilot or yaw damper is inoperative.

Removing Pitch Divergence

Pitch divergence is often encountered in aircraft directly after conversion from FS5 to FS98 format. Where the aircraft flew fine before, it will often diverge after. The shame is it normally occurs with beautifully detailed airliners, and, sometimes the problem cannot be fixed. Here’s how to detect the problem and how to try fixing it. The problem will be noticeable only after climbing above 30,000 ft and setting up cruise under the autopilot. The aircraft begins to settle into horizontal flight but as the speed increase toward normal cruise a slight pitch oscillation begins. After a few minutes it pitches so bad the autopilot runs the trim control to one extreme or the other. Pay close attention when first doing this with a new aircraft and interrupt the autopilot before the control reaches an extreme setting. Pause the flight and begin looking for a solution. Using FDE, open the aircraft’s .air file as well as the files of one or two similar aircraft that fly well. Compare the magnitudes of the Pitch Stability Factor 2. If the values for the good aircraft are similar but the one for the new aircraft is significantly larger or smaller, change it and resume the flight. This will probably result in a quick fix. Remember to re-Select Aircraft when resuming the paused and minimized FS98 so you will see the results of the change.

Sometimes the solution is more difficult. You may need to adjust both the Trim Pitch Factor (TPF) and the Pitch Stability Factor 2 (PSF2). Record all your changes and results on a sheet of paper. Make a change while pausing and minimizing FS with the aircraft flying at cruise conditions under autopilot but with trim settings near the middle of the range. Select the aircraft after making the edit and look carefully at the pitch behavior. When the settings are nearly right, it will take a while to verify the oscillation is indeed converging. It will always start a larger oscillation after any change but, looking at altitude values, you should see smaller and smaller amplitudes above or below a middle value (slightly below the altitude set). Unfortunately, the response to changes in PSF2 are not simple. There may be improvement over several changes and then the divergence gets worse. You will then have to make a big change (2x or 3x) in the PFS2 and try another sweep with small increments. The author chased this problem for two days on the Learjet 60. It was solved only by going back to the FS5 model, stiffening the pitch stability scalar there and then reconverting to FS98 and making small adjustments at both low altitude and high altitude / high speed. The pitch and yaw axes were

left a little loose at low speed while doing landing maneuvers. Also, a ceiling of 45,000 ft - not 51,000 ft - had to be accepted. There was a similar problem with the IAI Galaxy jet but persistence with adjustment of Pitch Stability Factor 2 solved the problems with only a slight reduction in ceiling.

Yaw/Roll Divergence or “Dutch Roll”

This is also a common problem with airliners but the solution is simple. Turn on the yaw damper any time you fly above 30,000 ft with a plane that has this tendency. Include a note to this effect in the checklist for the aircraft. Note that the yaw damper is marked y/d on the autopilot panel. It can be turned on without turning on the autopilot if you wish. Make sure you turn it off during descent when below 30,000 ft as it will not turn off with the autopilot. It may interfere with flight control during the approach if you leave it on. When this problem occurs you will see first a yaw oscillation that slowly diverges with accompanying roll oscillations that grow. It can lead to loss of control. This problem was found in a nice Cessna Caravan model downloaded recently. The model was well done except for the landing gear and a tendency to oscillate in roll under the control of the autopilot at low altitude. This was the first case of this problem at low altitude so we suspected a problem with some parameters. Attempts to adjust parameters failed to eliminate the problem, however. The yaw damper is needed whenever the autopilot is ON in that plane.

Divergent Breaks

This is a topic that has received some publicity lately because both the Air Force and the Navy have begun testing for it. It won't happen to you if you're flying a Learjet as though a corporate vice president is in the the back, but if you try over banking in a turn at max altitude you could find it. It normally occurs only in jet fighters doing high altitude maneuvers. What happens is a dynamic stall which flips the aircraft into a mode from which normal controls for recovery are totally ineffective. The plane can easily descend to impact turning lazily around inverted or spinning wildly. Even an ejection seat is not a guaranteed solution. One recovery technique is to time power surges with the rotation to break out into a dive. Once the nose is down in a dive, you can recover if you do so gently enough to avoid pulling the wings off or blacking out. Recovery can easily take 30,000 ft. There are definitely things you can do to a jet that will hurt both you and the jet. FS is a good place to examine this behavior. You can see an example if you download the Commander 840 turboprop aircraft. There is a Flight Video showing a dynamic stall at 10,000 ft from which the author did not recover. If you download the T-28b, you can see an airshow sequence in a Flight Video in which the plane flipped after a tail slide but did recover. Any time you get the nose down, you've won the battle. Of course, if you're out of altitude, you've lost the war!

Flight Dynamics by Tom Goodrick

Because there is no certain approach to the elimination of dynamic stability problems, you should be prepared to cease efforts after a high level of frustration is reached. There are many very nice aircraft available which can be flown easily for a relaxing time. Relagate the real tough problems to the back of the hangar for a day when you feel like taking on the “impossible.” If you can get a copy of FS5.1 with Flight Shop, you have a way of fixing just about any problem by going back to the beginning for a new air file. The author has an F-104 that has resisted even this treatment. He got it in FS5 originally where it was a basket case - prone to “flipouts” at moderate speed during high-bank turns. It did fly well finally in FS5 and FS95. Maybe someday it will fly in FS98 or FS2000.

APPENDIX

FDE PARAMETER LINES

The following is a list of the FDE parameter lines as contained in the Fdelist.txt file that comes with the FDE download. This list can be modified (in a certain way) by the user to change the listing seen when running FDE. It shows all the parameters in the same order as when running FDE. The section on Combat Flight Simulator parameters has been deleted.

1,,Aircraft Title,Text,40
2,,Aircraft Description,Text,1024
3,,Aircraft Specifications,Text,512
4,,Aircraft Tail Number,Text,8
100,,Aircraft Simulator Identifier,Text,8
101,,Aircraft Model Filename,Text,16
105,,Helicopter?,Boolean4,1

301,,Fuselage,Header,1
301,0,Cockpit View Right+/Left- C of G (inches),Integer2,6.5
301,2,Cockpit View Above+/Below- C of G (inches),Integer2,6.5
301,4,Cockpit View Fore+/Aft- C of G (inches),Integer2,6.5
301,6,Unknown 301-06,Integer2,1
301,8,Unknown 301-08,Integer2,1
301,10,Fuselage Angle,Integer2,182

302,,Fuel Capacity,Header,1
302,0,Fuel Tank Center (gallons),Integer4,1
302,4,Fuel Tank Left Main (gallons),Integer4,1
302,8,Fuel Tank Right Main (gallons),Integer4,1
302,12,Fuel Tank Left Aux (gallons),Integer4,1
302,16,Fuel Tank Right Aux (gallons),Integer4,1

310,,Engine Type (0=prop 1=jet 2=glider 3=helicopter),Integer1,1
311,,Number of Engines,Integer2,1
312,,Fuel Weight per gallon (lbs),Integer2,256
313,,Reverse Thrust (%),Integer2,163.84
314,,Land Me?,Boolean2,1
315,,Flaps Position,Integer2,1
316,,Max Speed (Mach),Integer4,20480

317,,Autopilot,Header,1
317,0,Autopilot?,Boolean4,1
317,4,Vertical Speed Hold?,Boolean4,1
317,10,Vertical Speed Ascend/Descend (FPM),Integer2,1

318,,Flaps?,Boolean4,1
319,,Monoplane?,Boolean4,1

322,,Mixture Control?,Boolean4,1

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323,,Carburetor Heat?,Boolean4,1
324,,Unknown 324-00,Boolean4,1

325,,Unknown Section 325,Header,1
325,0,Unknown 325-00,Integer4,1
325,4,Unknown 325-04,Integer4,1
325,8,Unknown 325-08,Integer4,1
325,12,Unknown 325-12,Integer4,1
325,16,Unknown 325-16,Integer4,1
325,20,Unknown 325-20,Integer4,1

327,,Spoilers?,Boolean4,1
328,,Taildragger?,Boolean4,1

329,,Unknown Section 329,Header,1
329,0,Unknown 329-00,Integer4,1
329,4,Unknown 329-04,Integer4,1
329,8,Unknown 329-08,Integer4,1

330,,Propeller Type (1=Fixed 2=Constant Speed),Integer4,1
331,,Pitot Heat?,Boolean4,1
332,,Wheel Brakes?,Boolean4,1

333,,Unknown 333,Header,1
333,0,Unknown 333-00,Integer4,1
333,0,Unknown 333-04,Integer4,1

334,,Unknown 334-00,Integer4,1

335,,Navigation Instrument,Header,1
335,0,VOR 1?,Boolean4,1
335,4,VOR 2?,Boolean4,1
335,8,OMI?,Boolean4,1

500,,Reciprocating Engine,Header,1
500,0,Oil Pressure Factor,Integer2,3
500,2,Oil Temperature Factor,Integer2,4096
500,14,Maximum RPM,Integer2,2
500,16,Propeller Pitch Max (degrees),Integer2,182
500,18,Propeller Pitch Min (degrees),Integer2,182
500,30,Maximum Power (horsepower - each),Integer2,1
500,32,Fuel Consumption Factor,Integer2,1
500,34,Prop Diameter (inches),Integer2,1
500,36,Unknown 500-36,Integer2,1
500,38,Unknown 500-38,Integer2,1
500,40,Unknown 500-40,Integer2,1
500,42,Unknown 500-42,Integer2,1
500,44,EGT Factor,Integer2,5120
500,46,Power Scalar,Integer2,1
500,62,RPM Scalar (min),Integer2,1
500,64,RPM Scalar (max),Integer2,1

600,,Jet Engine,Header,1
600,0,Oil Pressure Factor,Integer4,42

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600,4,Oil Temperature Factor,Integer4,101.966
600,8,Oil Viscosity/Temp,Integer4,1
600,12,Thrust Vector (degrees),Integer4,182
600,16,Peak Efficient Altitude (feet),Integer4,1
600,20,Unknown 600-20,Integer4,1
600,24,N1 Inertia (fan),Integer4,1
600,28,N2 Inertia (turbine),Integer4,1
600,32,Fuel Consumption/TSFC,Integer4,1
600,36,Fuel Consumption Base,Integer4,1
600,40,Turbine Temperature Base,Integer4,1
600,44,Thrust Factor,Integer4,1
600,48,Starter Speed,Integer4,1
600,52,Starter Cutout Speed,Integer4,1
600,56,Idle Throttle Adjust,Integer4,1
600,60,Max Throttle Adjust,Integer4,1
600,64,Flameout Altitude (meters),Integer4,1
600,68,Thrust Maximum (pounds - each),Integer4,0.073167
600,72,Turbine Temperature Scalar,Integer4,256
600,76,Compressor Factor,Integer4,512

1001,,Aerodynamics - Weight & Balance,Header,1
1001,0,Moment of inertia - roll,Integer4,1
1001,4,Moment of inertia - pitch,Integer4,1
1001,8,Moment of inertia - yaw,Integer4,1
1001,12,Roll Damping Factor,Integer4,1

1002,,Engine Locations,Header,1
1002,0,Engine 1 Position Right+/Left- C of G (inches),Integer4,1
1002,4,Engine 1 Position Above+/Below- C of G (inches),Integer4,1
1002,8,Engine 1 Position Fore+/Aft- C of G (inches),Integer4,1
1002,12,Engine 2 Position Right+/Left- C of G (inches),Integer4,1
1002,16,Engine 2 Position Above+/Below- C of G (inches),Integer4,1
1002,20,Engine 2 Position Fore+/Aft- C of G (inches),Integer4,1
1002,24,Engine 3 Position Right+/Left- C of G (inches),Integer4,1
1002,28,Engine 3 Position Above+/Below- C of G (inches),Integer4,1
1002,32,Engine 3 Position Fore+/Aft- C of G (inches),Integer4,1
1002,36,Engine 4 Position Right+/Left- C of G (inches),Integer4,1
1002,40,Engine 4 Position Above+/Below- C of G (inches),Integer4,1
1002,44,Engine 4 Position Fore+/Aft- C of G (inches),Integer4,1

1003,,Fuel Tank Locations,Header,1
1003,0,Center Fuel Tank Position Right+/Left- C of G (inches),Integer4,1
1003,4,Center Fuel Tank Position Above+/Below- C of G (inches),Integer4,1
1003,8,Center Fuel Tank Position Fore+/Aft- C of G (inches),Integer4,1
1003,12,Main Fuel Tank Position Right+/Left- C of G (inches),Integer4,1
1003,16,Main Fuel Tank Position Above+/Below- C of G (inches),Integer4,1
1003,20,Main Fuel Tank Position Fore+/Aft- C of G (inches),Integer4,1
1003,24,Aux Fuel Tank Position Right+/Left- C of G (inches),Integer4,1
1003,28,Aux Fuel Tank Position Above+/Below- C of G (inches),Integer4,1
1003,32,Aux Fuel Tank Position Fore+/Aft- C of G (inches),Integer4,1

1004,,Landing Gear Position,Header,1
1004,0,Retractable?,Boolean4,1
1004,4,Steerable?,Boolean4,1

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1004,8,Main Gear Position Right+/Left- C of G (inches),Integer4,1
1004,12,Main Gear Position Above+/Below- C of G (inches),Integer4,1
1004,16,Main Gear Position Fore+/Aft- C of G (inches),Integer4,1
1004,20,Nose/Tail Gear Position Right+/Left- C of G (inches),Integer4,1
1004,24,Nose/Tail Gear Position Above+/Below- C of G (inches),Integer4,1
1004,28,Nose/Tail Gear Position Fore+/Aft- of C of G (inches),Integer4,1
1004,32,Nose/Tail Gear Cycle Time (seconds),Float8,1
1004,40,Left Main Gear Cycle Time (seconds),Float8,1
1004,48,Right Main Gear Cycle Time (seconds),Float8,1
1004,56,Nose/Tail Gear Max Loading Weight,Integer4,1
1004,60,Nose/Tail Gear Min Loading Weight,Integer4,1
1004,64,Nose/Tail Gear Crash Factor,Integer4,1
1004,68,Main Gear Max Loading Weight,Integer4,1
1004,72,Main Gear Min Loading Weight,Integer4,1
1004,76,Main Gear Crash Factor,Integer4,1

1005,,Scrape Points Position,Header,1
1005,0,Front Scrape Point Right+/Left- C of G (inches),Integer4,1
1005,4,Front Scrape Point Above+/Below- C of G (inches),Integer4,1
1005,8,Front Scrape Point Fore+/Aft- C of G (inches),Integer4,1
1005,12,Front Scrape Point Crash Factor,Integer4,1
1005,16,Rear Scrape Point Right+/Left- C of G (inches),Integer4,1
1005,20,Rear Scrape Point Above+/Below- C of G (inches),Integer4,1
1005,24,Rear Scrape Point Fore+/Aft- C of G (inches),Integer4,1
1005,28,Rear Scrape Point Crash Factor,Integer4,1
1005,32,Side Scrape Point Right+/Left- C of G (inches),Integer4,1
1005,36,Side Scrape Point Above+/Below- C of G (inches),Integer4,1
1005,40,Side Scrape Point Fore+/Aft- C of G (inches),Integer4,1
1005,44,Side Scrape Point Crash Factor,Integer4,1

1101,,Main Dynamics,Header,1
1101,0,Panel Type,Integer2,1
1101,2,Stall Speed (knots),Integer2,1
1101,4,Vmo,Integer4,128
1101,28,Max Dry Weight Full Fuel,Integer4,1
1101,38,Braking Factor,Integer2,1
1101,48,Drag Coefficient - Zero Lift,Integer2,2048
1101,50,Drag Coefficient - Flaps,Integer2,2048
1101,52,Drag Coefficient - Landing Gear,Integer2,2048
1101,54,Drag Coefficient - Spoiler,Integer2,2048
1101,80,Drag Scalar (Template) Factor,Integer2,1
1101,90,Pitch Stability Factor 1,Integer2,1
1101,92,Horizontal Stabilizer Lift,Integer2,1
1101,94,Flaps Lift,Float8,1
1101,102,Spoiler Lift,Float8,1
1101,110,Dihedral (degrees),Integer2,182
1101,112,Aileron Lift,Integer2,1
1101,114,Yaw Stability Factor 1,Integer2,1
1101,118,Roll Stability Factor 1,Integer4,1
1101,134,Unknown 1101-134,Integer4,1
1101,138,Unknown 1101-138,Integer4,1
1101,142,Elevator Control Factor,Integer4,1
1101,150,Pitch Stability Factor 2,Integer4,1
1101,170,Pitch Trim Factor,Float8,1

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1101,178,Flaps Pitch Factor,Float8,1
1101,186,Gear Pitch Factor,Float8,1
1101,194,Spoiler Pitch Factor,Float8,1
1101,202,Unknown 1101-202,Integer2,1
1101,204,Unknown 1101-204,Integer2,1
1101,206,Unknown 1101-206,Integer2,1
1101,208,Unknown 1101-208,Integer2,1
1101,228,Yaw Stability Factor 2,Integer4,1
1101,232,Yaw Stability Factor 3,Integer2,1
1101,234,Unknown 1101-234,Integer2,1
1101,236,Roll Stability Factor 2,Integer2,1
1101,238,Yaw Stability Factor 4,Integer2,1
1101,240,Yaw Stability Factor 5,Integer2,1

1202,0,Yaw Damping Factor,Integer4,1

1203,,Unknown Section 1203,Header,1
1203,0,Unknown 1203-00,Float8,1
1203,8,Unknown 1203-08,Float8,1
1203,16,Unknown 1203-16,Float8,1
1203,24,Unknown 1203-24,Float8,1
1203,32,Unknown 1203-32,Integer2,1
1203,34,Unknown 1203-34,Integer2,1

1204,,Main Wing,Header,1
1204,0,Main Wing Area (sq.feet),Integer4,1
1204,4,Main Wing Span (inches),Integer4,1
1204,8,Main Wing Chord (inches),Integer2,1
1204,10,Unknown 1204-10,Integer2,1
1204,12,Main Wing Dihedral (degrees),Integer2,182
1204,16,Main Wing Chord Angle (degrees),Integer2,182
1204,20,Unknown 1204-20,Integer2,1
1204,22,Main Wing Position Fore+ /Aft- of C of G (inches),Integer4,1
1204,24,Winglet?,Boolean4,1

1205,,Horizontal Stabilizer,Header,1
1205,0,Horizontal Stabilizer Area (sq.feet),Integer4,1
1205,4,Horizontal Stabilizer Span (inches),Integer4,1
1205,8,Horizontal Stabilizer Position Fore+ /Aft- of C of G (inches),Integer4,1
1205,12,Horizontal Stabilier Efficiency Factor,Integer4,1

1206,,Vertical Stabilizer,Header,1
1206,0,Vertical Stabilizer Area (sq.feet),Integer4,1
1206,4,Vertical Stabilizer Height (inches),Integer4,1
1206,8,Vertical Stabilizer Position Fore+ /Aft- C of G (inches),Integer4,1
1206,12,Vertical Stabilizer Efficiency Factor,Integer4,1