Weight & Balance

Section VI

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GENERAL

An aircraft is designed to be flown in a properly loaded condition. What this means to the home builder is that their newly constructed aircraft is a total unknown prior to its first flight and as such must be given a thorough weight and balance review. A mandatory part of this is a trip to the scales. A more complete coverage of this subject can be found in the FAA Aviation Circular AC 91-23A (from which much of this material comes).

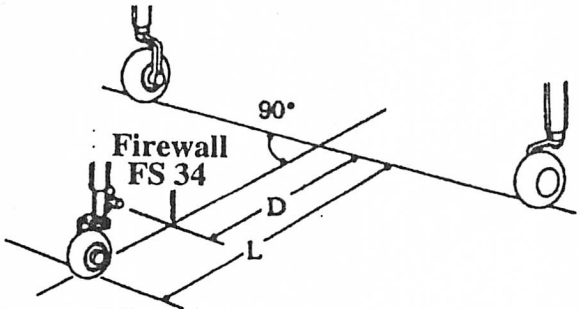
Prior to the scales the machine must be virtually complete. It should be painted, have a finalized List of Equipment which identifies all those add-ons to the basic airframe that may be changed later on such as wheels and brakes, battery, propeller, spinner, alternator, even the engine. Ideally, the engine will have been checked out and the fuel tanks drained to provide a real unusable fuel remaining. Oil should be as you will use it, i.e. full. This List of Equipment will come in handy and possibly prevent another trip to the scales should you decide to upgrade later to that 6 cylinder whiz banger that is out of reach without having won the lotto yet. It should include most (if not all) the instrument panel goodies too; in short, be as close to equipped the way you will fly it as possible.

Why worry about the cg? The forward position is that limit where you will still have enough elevator control authority to flare the aircraft for landing. It would be more than embarrasing to be reducing the speed on final only to find out that you are suddenly unable to keep the nose from pitching down and you can't stop it!!! On the other end, the aft limit affects both the low and high end of

the speed range. On take-off you could rotate and be unable to limit the pitch angle thus putting you on "the back side", where, again you don't have the control authority needed.

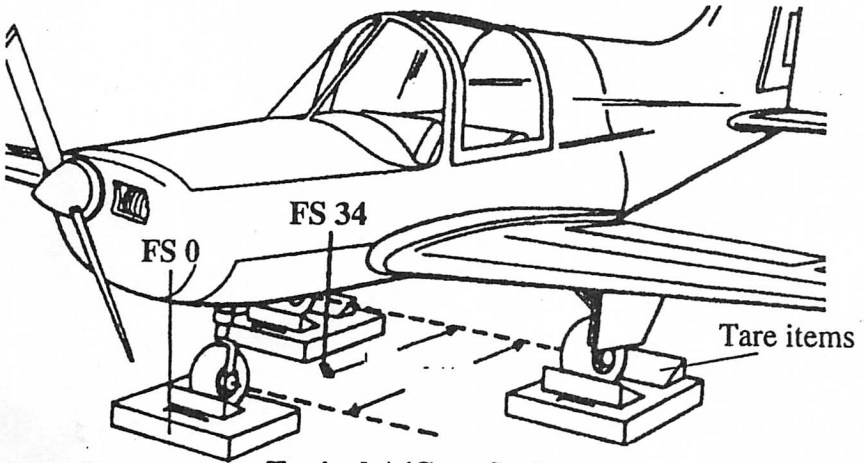
On the high speed end, the longitudinal stability of the machine becomes excessively sensitive to the point that overstressing of the aircraft is almost probable. Needless to say these are real limits. Thus there is more to the admonition to "LIVE BETWEEN THE LIMITS".

WEIGHING THE PLANE



Measurements Required

Assuming you'll use the forward face of the firewall, FS 34 as a reference for locating the datum FS = 0 (a datum can be any location that you can relate to the aircraft station numbers which define the cg station limits, i.e. FS 76.00 to 84.00), the first task is to measure the reaction points. The figure here shows



Typical A/C on Scales

this pictorially. This measurement need$ to be made with the aircraft in a level attitude, both fore and aft and laterally. The firewall should be vertical to provide the former, the latter by measuring the wing tip to floor distances. Any tare items such as 1x6's needed on the scales to level the plane of course are subtracted from the scales indicated weight. Letting air out of the tires can be used for final trimming. A plumb bob, chalked string, a carpenters square, a good steel tape measure, and a means of marking the hangar floor are all that are required.

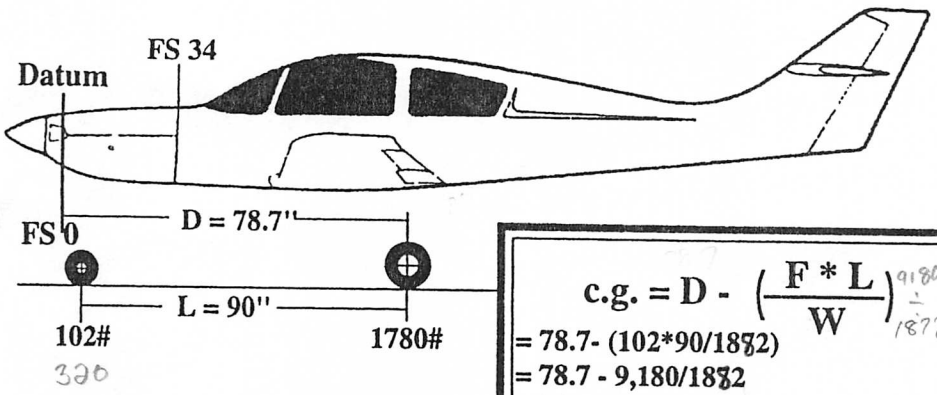
For the ~~Express~~, using FS 0 as the datum, any moments forward of the datum are negative, those aft are positive. For example, if the point of the spinner is used as the datum, all moments would be positive because all locations are aft of this point. Either method is acceptable providing the chosen datum is related to the Fuselage Station and the sign of the moment is correctly maintained. All weights are positive of course. Using FS 0 which is forward of the nose wheel, all scale weights and moments are positive.

Once on the scales the loads on each of the scales can be related to the measured dimensions to provide the moments. A closed hangar (or a virtually calm day) are needed to reduce scale errors. Multiple readings are desirable because they can be averaged out and any scale calibration factor or error applied to the readings. If time permits, it is also desirable to put a "pilot" and then an aft passenger in the plane to confirm the station number moments.

Time and hangar rules permitting, the fuel tanks can be filled in increments providing both a four or five point gauge calibration and additional weight data.

FINDING YOUR CG

Two methods can be used to find your cg. Adding up the weight measured by each of the scales, left, right and nose will provide the empty weight. Multiplying the weight on each scale by the distance to the datum provides the moment arm in inch-pounds.



$$c.g. = D - \left(\frac{F * L}{W}\right)$$

= 78.7- (102*90/1882)
= 78.7 - 9,180/1882
= 78.7 - 4.9 = 73.8" datum to c.g.

Therefore = c.g. is at FS 73.8

WHERE, for EXAMPLE:

W = total weight of a/c, **1780 + 102 = 1882#**

D = datum to main wheel weighing point = **78.7 in.**

L = distance main wheel to nose wheel = **90 inches**

F = weight at nose wheel weighing point = **102#**

Then;

c.g. = distance from datum to c.g. of the a/c

For the *Express*, using the FS 0 as a datum, the nose wheel weight and moments are positive. (Again, the weight is always positive.) A propeller for example would be positive in weight and negative in moment. Once the weights have been totaled to the empty weight, and the main and nose gear moments added up, the

resulting total moment, when divided by the empty weight, results in the dimension, in inches, from the datum to the center of gravity.

The example above shows an alternate method of finding your empty c.g. from your weighing. The numbers used are only approximate, and relate to the measurements made as shown on page 4.

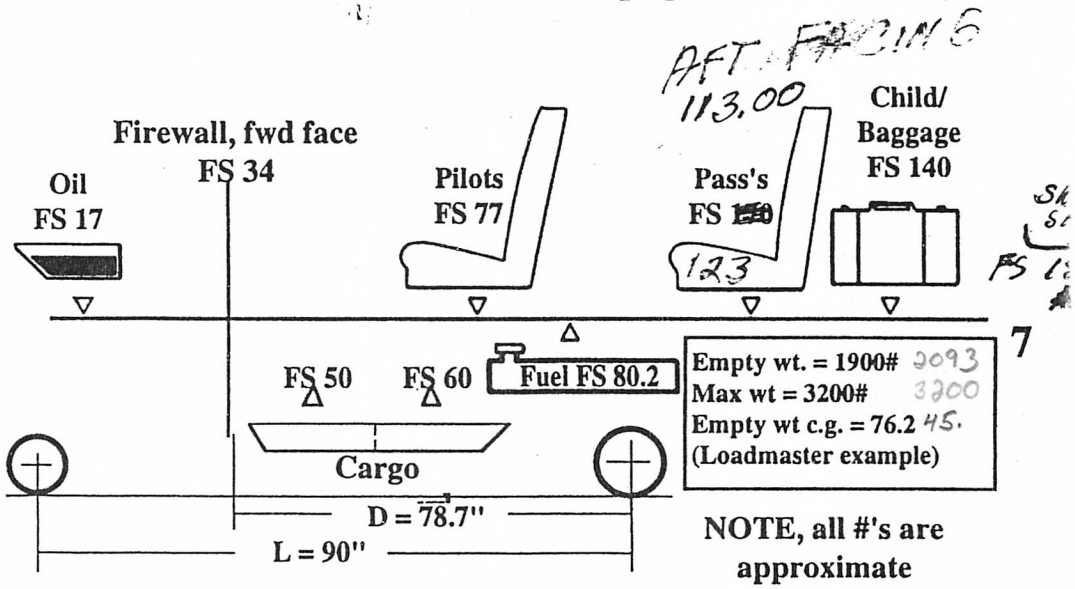


Diagram of Typical Arms for the Aircraft

FINDING YOUR USEFUL LOAD

With these data in hand we can now compare the weight of the empty aircraft with the maximum allowable gross weight for your model, the difference being your useful load! The cg position can be compared to the allowable range (76.00 to 84.00) and you now know where your empty cg is located. It is generally desirable to have the empty cg near the forward limit as most of the additional weight to be added will drive the cg aft.

It is a prudent thing to measure the arms of all the seats

in the plane to define their real location. Seats can vary in their actual moment arm (position) quite a bit depending on the angle of the backrest. There is a simple technique to actually measure this arm if you have made the seats removeable (or they can be mocked up after the fact by recreating the seat configuration out of plywood and similar cushion material) the seat c.g. location can be measured by using the "roller" method. This involves the use of a piece of pipe on a hard surface to see where the seat balance position is with both a light (like a child) and a heavy person in the "seat". The resulting balance position is then used to support the forward and aft calculations described below. The roller technique shown here is also used for cargo and pod loading. To keep the cargo or seat near level or with the seat in the normal position, three pipes can be used such as two 1/2 inch on each end and a 3/4 inch in the middle. In this manner the seat back will maintain nearly the same tilt as in the plane.

LOADING CHECKS

For owners of the Loadmaster in particular, two other checks are in order, i.e. the forward and aft extreme loading cg's. When a forward extreme condition check is made, the objective is to establish that neither the maximum weight limit nor the forward c.g. limit is exceeded. Normally, this check is made assuming both front seats are occupied (with heavy pilots), the rear seats and baggage empty, and the pod loaded forward. Since the fuel tanks are located aft of the forward limit they would be with minimum (for landing) fuel. A similar check is made for the aft loading, a single (small) pilot, maximum passengers and pod aft, and maximum fuel. Again for the Loadmaster, the pod loading will provide the ability to load the aircraft such that the cg is maintained

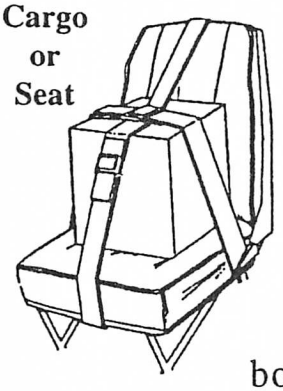
within limits. Time spent laying out loading scenairos ahead of time will insure that the gross weights and the cg's you fly with are safe.

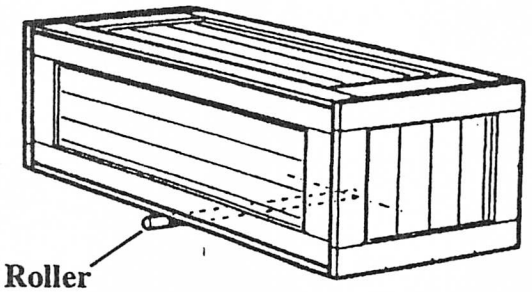
After the weighing, and the forward and aft loading limit checks described above, you may find that is is desirable to ballast the aircraft, and can now define the minimum amount needed (at the maximum arm) to make the best use of your useful load.

Weights to be used in these calculations are 6 lb/U.S. gallon for gasoline and 7.5 lb/U.S. gallon for oil. Water for you liquid engine guys is 8.35 lb/U.S. gallon. Pilots and passengers are figured as actual, or 170 lb each, adding 5# for winter clothes, and baggage as actual.

CARGO

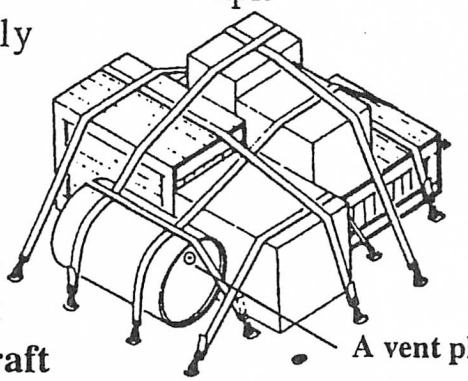
If you intend to use your Express for cargo, some hints follow to help you control and maintain your cg where it must be for safe operation. Establishing the cg of the cargo with a roller is a start. If the cargo is to be placed in a seat, strap it in as shown and estimate the change to the seats arm for its new moment. The rear seat area and pod should both be provided with means of securing their load to prevent it shifting during climb or descent and putting the aircraft out of range.





Finding cg Using a Roller

Liquid containers should be placed with the opening up, and a vent is normally prudent to allow pressures to equalize with altitude. Hot coffee thermos containers in the cockpit have become notoriously dangerous.



NOTE

The FAA regulations require that at least one aircraft weight and balance sheet be carried in the aircraft at all times.

You should complete a loading schedule for your Pilots Operating Handbook (POH). While not required by the FAA, it may be elsewhere, and it is nonetheless useful and you now have the information for the following;

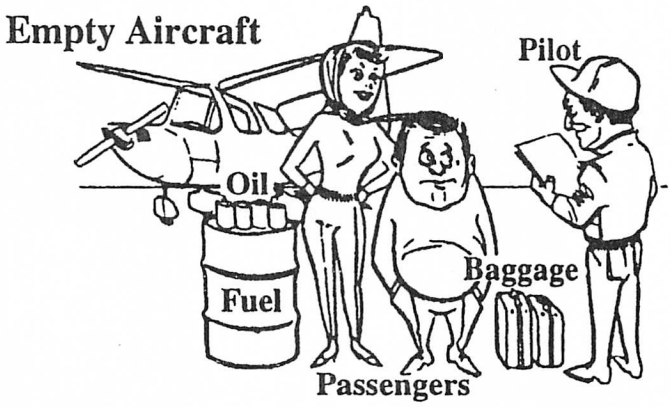
a) Limitations and data
   1) The max. allowed gross weight (2895# or 3200#)
   2) The empty weight and cg
   3) The useful load
   4) The composition of the useful load, including fuel and oil with full tanks

b) Load distribution:
   The established cg limits, furnished by Express Design Inc. and enough information to indicate loading combinations that will keep the cg within the established limits.

A number of charts have been included for your use. Upon obtaining the data, first use copies of the charts for your information, then make final charts to include herein.

A Weight & Balance SHEET
A Weight & Balance RECORD
An Aircraft Equipment List, and
A Loading Graph.

This may seem like an overkill to weight and balance, however it is not and in reality, is just the opposite. To keep the flying characteristics of your aircraft safe and controllable this is about the minimum for a first flight, and will suffice for many equipment changes thru the life of the plane. You can rest assured, as can your passengers, that the best is flying the best, an Express.



Remember
You are in control
Their lives are in your hands

DEFINITIONS

The student of weight and balance needs to be familiar with terms used in publications related to many aspects of the subject. These terms are fairly well standardized; however, only terms related to general aviation aircraftare shown here.

1. **Arm (moment arm)**—is the horizontal distance in inches from the reference datum line to the center of gravity of the item. The algebraic sign is plus (+) if measured aft of the datum, and minus (—) if measured forward of the datum.

2. **Center of gravity (c.g.)**—is the point about which an aircraft would balance if it were possible to suspend it at that point. It is the mass center of the aircraft, or the theoretical point at which the entire weight of the aircraft is assumed to be concentrated. It may be expressed in percent of MAC (mean aerodynamic chord) or in inches from the reference datum.

3. **Center of gravity limits**-are the specified forward and aft points beyond which the c.g. must not be located during takeoff, flight or landing. The limits are indicated on pertinent FAA aircraft type certificate data sheets, specifications, or weight and balance records, and meet the requirements of Federal Aviation Regulations.

4 **Center of gravity range-** is the distance between the forward and aft c.g. limits indicated on pertinent aircraft specifications.

5 **Datum (reference datum)**—is an imaginary vertical plane or line from which all measurements of arm are taken. The datum is established by the manufacturer [for builders, thats you]. Once the datum has been selected, all moment arms and the location of permissible c.g. range must be taken with reference to that point.

6. **Delta**—is a Greek letter expressed by the symbol Δ. It is used in weight and balance calculations, as well as in other forms of mathematics, to indicate a change of values. As an example, Δ c.g. indicates a change (or movement) of the c.g.

7. **Fuel load**—is the expendable part of the load of the aircraft. It includes only usable fuel, not fuel required to fill the lines or that which remains trapped in the tank sumps.

8. **Moment**—is the product of the weight of an item multiplied by its arm. Moments are expressed in pound-inches (lb-in.) or inch-pounds. Total moment is the weight of the aircraft multiplied by the distance between the datum and the c.g.

9. **Moment index (or index)**—is a moment divided by a constant such as 100, 1,000, or 10,000. The purpose of using a moment index is to simplify weight and balance computations of large aircraft where heavy items and long arms result in large, unmanageable numbers.

10. **Mean aerodynamic chord (MAC)** - is the average distance from the leading edge to the trailing edge of the wing. The MAC is specified for the aircraft by determining the average chord of an imaginary wing which has the same aerodynamic characteristics as the actual wing.

11. **Reduction factor** - is the constant which when divided into a moment results in an index. Reduction factors of 100, 1,000, or 10,000 are used to simplify weight and balance calculation processes.

12. **Standard weights**—have been established for numerous items involved in weight and balance computations. The weights are not to be used in lieu of available actual weights. Some of the standard weights are:

General Aviation crew and passengers 170#
Gasoline.....6 #/U.S. gal.
Oil.....7.5 #/U.S. gal.
Water.....8.35 #/U.S. gal.

Weight & Balance Report

Empty Weight c.g.

	Scale	Tare	Net	Arm	Moment
Left Jack/Wheel	____	____	____	____	_____
Right Jack/Wheel	____	____	____	____	_____
Nose Wheel	____	____	____	____	_____
Totals	Empty Wt.		_____		_____

Mom. Tot./Wt. = _____ in. aft of datum

Weight & Balance Report

Empty Weight c.g.

	Scale	Tare	Net	Arm	Moment
Left Jack/Wheel	____	____	____	____	_____
Right Jack/Wheel	____	____	____	____	_____
Nose Wheel	____	____	____	____	_____
Totals	Empty Wt.		_____		_____

Mom. Tot./Wt. = _____ in. aft of datum

Weight & Balance RECORD

Express ______			Serial No., ________,				N ________,			Page ___	
Date	Item No.		Description of Article or Modification	Weight Change						Basic Empty Weight	Basic Empty Moment
				Added (+)			Removed (-)				
	In	Out		Wt~#	Arm~In	Mom.	Wt~#	Arm~In.	Mom.		

Express™

Weight & Balance RECORD

Express ____ | Serial No., ________, | N ________, | Page ___

Date	Item No.		Description of Article or Modification	Weight Change						Basic Empty Weight	Basic Empty Moment
				Added (+)			Removed (-)				
	In	Out		Wt~#	Arn~In	Mom.	Wt~#	Arn~In.	Mom.		

Basic Aircraft Empty Weight _____		
Empty Moment _____		
Occupants		
Weight ~ #	**Arm**	**Moment**
170 - pilot 170 - copilot		
170 - pass #1 170 - pass #2		
50 - child #1 50 - child #2		
50 - cabin baggage		

Fuel - (U.S. Gallons)			
Gallons	**Weight**	**Arm**	**Moment**
10 gal	60#		
20	120		
30	180		
40	240		
50	300		
60	360		
70	420		
80	480		
90	540		
100`	600		

Baggage, Pod		
25 # Fwd 50 75		
25 Mid 50 100		
25 Aft 50 100		

Weight & Balance LOADING FORM

My Aircrafts' Equipment List

Express

Serial Number _____ **Registration No.** _____

Date _____

(Add new date on next line when adding/removing equipment)

Item No.	Item Description	√ if Inst'ld Date inst'ld	Arm (In.)	Weight Lbs

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Aircraft Equipment List

My Aircrafts' Equipment List

Express

Serial Number _____ Registration No.

_____

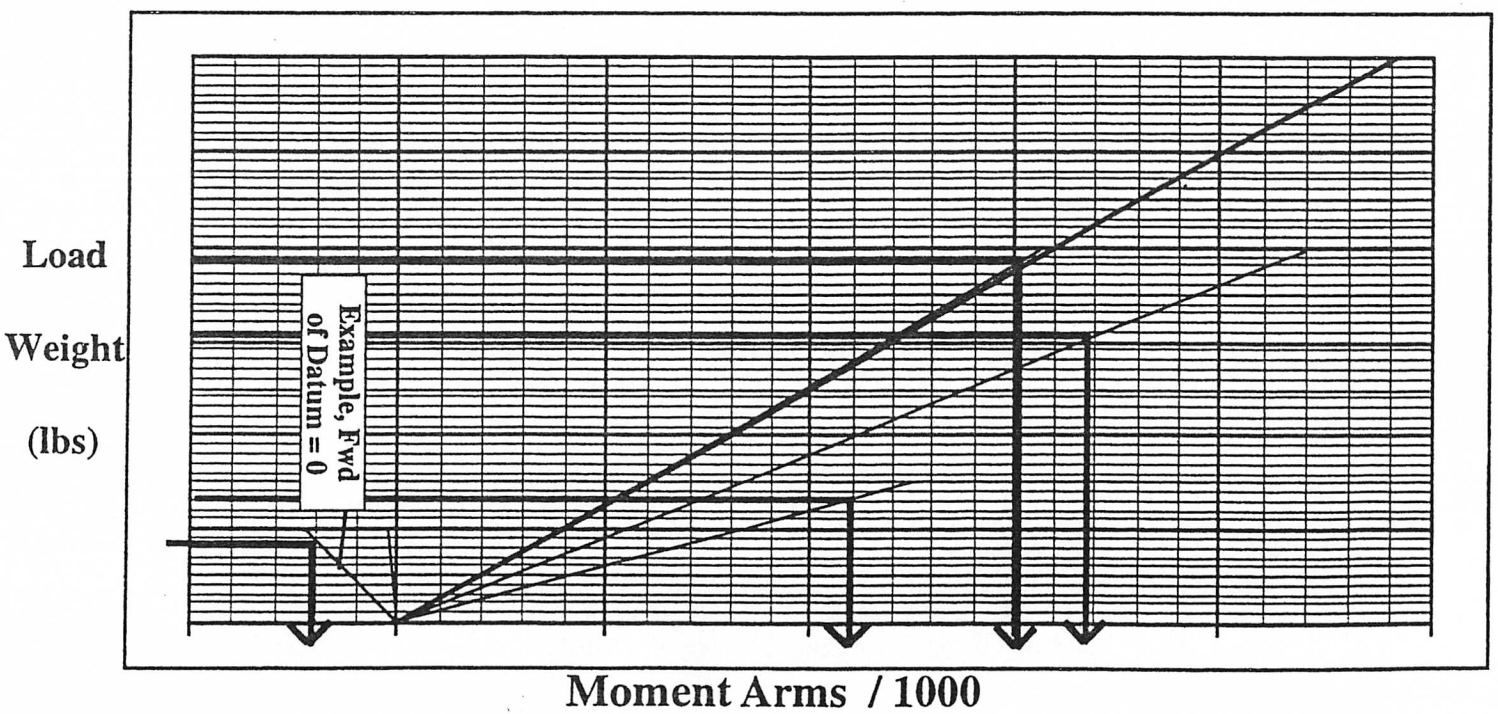
Date _____

(Add new date on next line when adding/removing equipment)

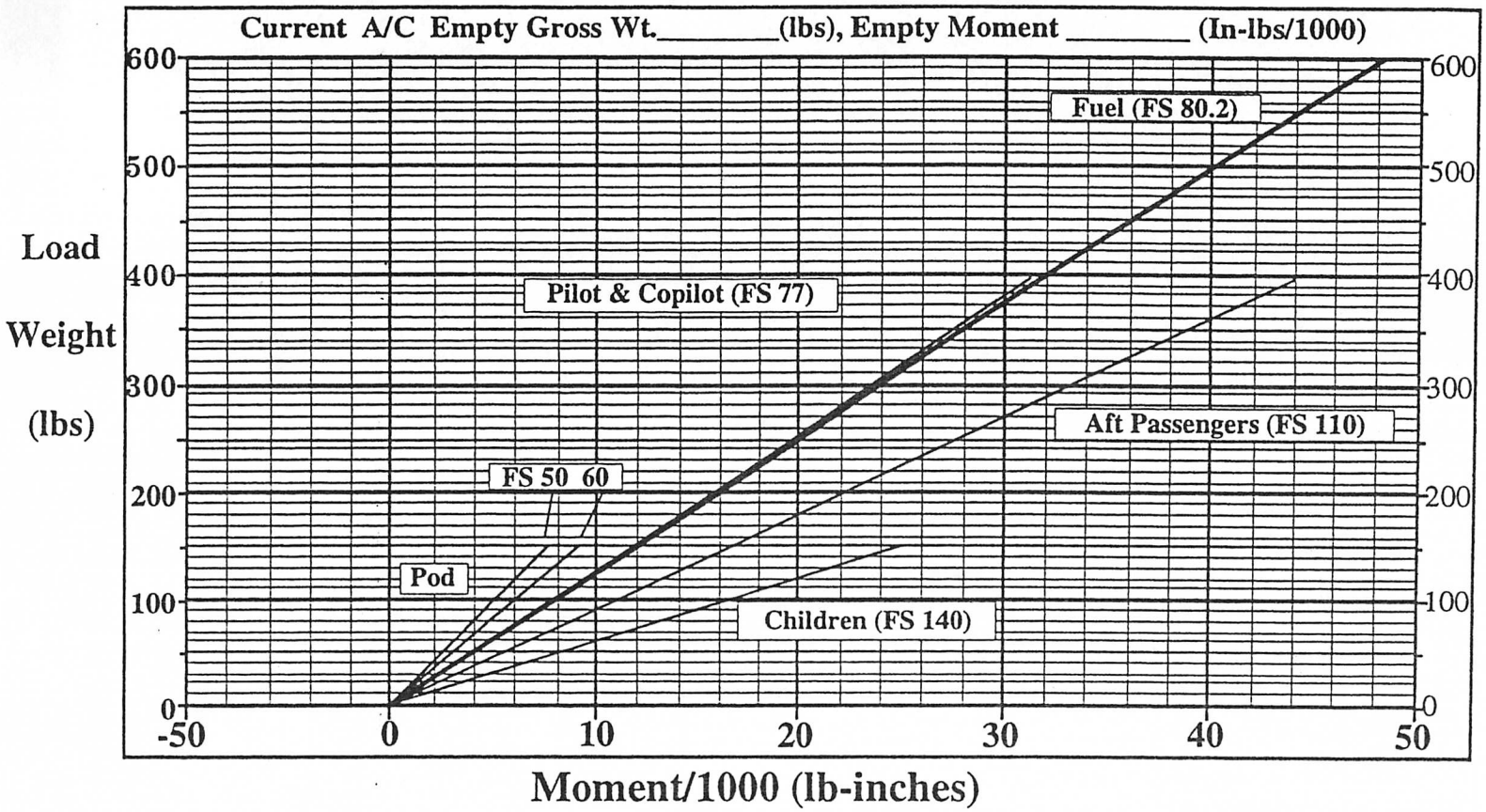
Item No.	Item Description	√ if Inst'ld Date inst'ld	Arm (In.)	Weight Lbs

Aircraft Equipment List (contunied)

Enter on left at the Load Weight, move horizontally right to the appropriate time then straight down to the moment/1000 value. Add both the weight and the moment to the Aircraft Empty Weight and Moment. Continue with each Load (fuel, fwd and aft passengers, baggage, and total all weights and moments. Divide the resulting Moment by the total Weight to find the Aircraft c.g. Plot this point on the Aircraft C.G. envelope, Page 22. **This must lie within the Acceptable Flight Envelope.**

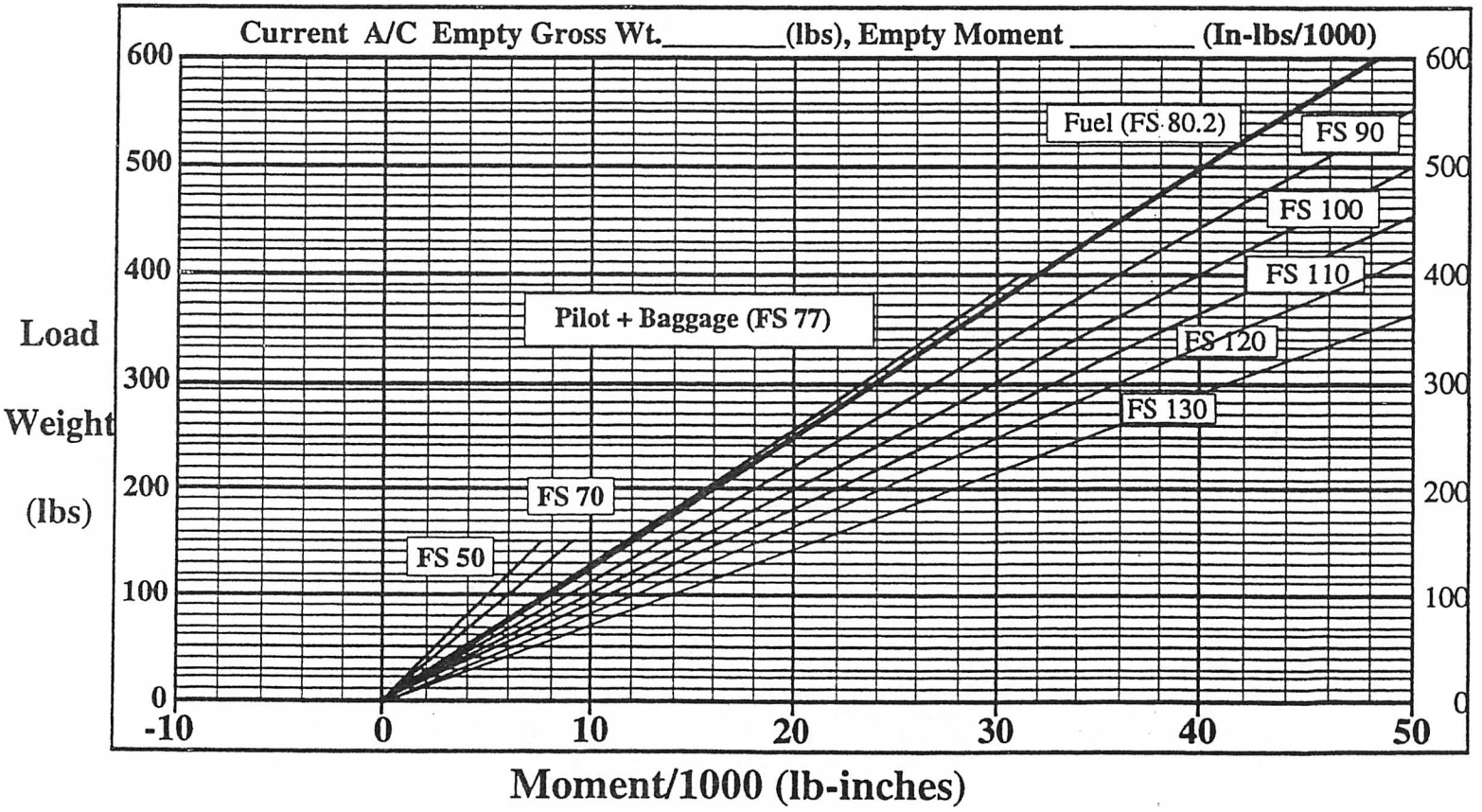


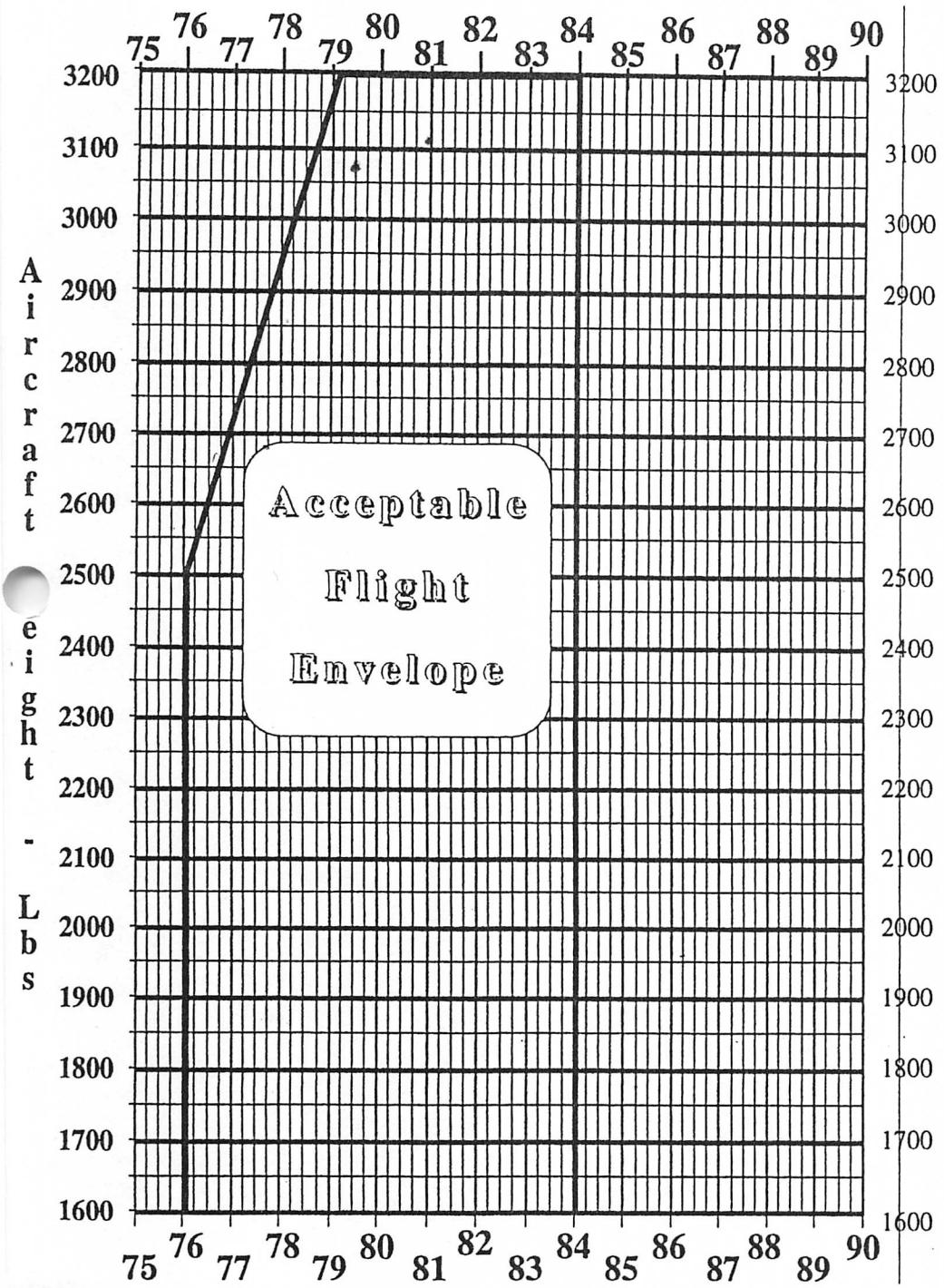
Loading Graph Club Seating



Express

Loading Graph - Loadmaster 3200





Aircraft C.G. - Aft of Datum

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