Weight and Balance

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Gleim sections 5.7-9

Weight and Balance

- *Weight* is the total weight of the aircraft as loaded (people, baggage, fuel, etc.)
  - *Maximum ramp weight* is the most weight the aircraft can support while sitting on the ramp (usually a structural limitation on the fuselage)
  - *Maximum takeoff weight* is the most weight the aircraft can support while taking off (usually a structural limitation on the fuselage or wings)
  - *Maximum landing weight* is the most weight the aircraft can support while landing (usually a structural limitation of the landing gear or fuselage)
  - Excess weight may cause structural failure or loss of takeoff and climb performance
- *Balance* is the location of the center of gravity
  - While the center of gravity really exists at a particular point in three dimensions, only the location along the longitudinal axis is considered in this case
  - The center of gravity (c.g.) is measured from an arbitrary point on the centerline of the airframe – usually the front of the propeller or the engine firewall – called the *reference datum*
  - For each weight, there is a legal range for the center of gravity
  - If within limits, a forward c.g. will cause:
    - An increase in stability
    - A slight reduction in airspeed
    - A higher stall speed
    - An improvement in the ability to recover from a stall
    - A slightly more difficult flare during landing
  - If within limits, a rearward c.g. will cause:
    - A decrease in stability
    - A slight increase in airspeed
    - A lower stall speed
    - A reduction in the ability to recover from a stall
    - An easier flare during landing
  - A c.g. forward of the forward limit (nose heavy) may prevent the airplane from flaring on landing (hitting nosewheel first)
  - A c.g. behind the aft limit (tail heavy) is very dangerous and may cause:
    - Inability to recover from a stall
    - A non-recoverable flat spin when a spin is entered
    - In extreme cases, static instability and complete loss of pitch control (when the c.g. is behind the center of lift)

Contributions to Weight and Balance

- The *empty weight* of an aircraft includes:
  - The aircraft itself
  - All permanently installed equipment
  - Unusable fuel
  - Full oil (note that the FAA question on this subject says “undrainable oil”, and is wrong for modern airplanes)
- *Fuel* weighs 6 pounds per gallon
- *Oil* weighs 7.5 pounds per gallon

- *Crew* (pilot, copilot)
- *Passengers* (front seat, middle seats, rear seats)
- *Baggage* (various baggage compartments)
- *Portable equipment* in the cabin – flight bags, food, towbar, etc.

Computing W&B Mathematically

- The *moment* of a particular object is the *weight* of that object multiplied by the *arm* for the location where the object is located
- The arm can be determined by looking in a table
- A positive arm is aft of the reference datum, and a negative arm is forward of the reference datum
- Because the moment can be large numerically, it is sometimes divided by 100 or 1000
- To compute weight and balance:
  1. Calculate the total weight (empty weight plus fuel plus people plus baggage)
  2. Check that the total weight is within weight limits
  3. For each object in the total weight, calculate the moment
  4. Add up the moments to find the total moment
  5. Divide the total moment by the total weight to find the c.g.
  6. Check that the c.g. is within limits for the given total weight

Example

Empty weight: 1500 pounds
Empty C.G.: 42 in
Maximum weight: 2500 pounds
C.G. forward limit (all weights): 45 in
C.G. aft limit (all weights): 55 in

Item	Weight	Arm	Moment
Empty weight	1500	42	63000
Pilot	170	48	8160
Rear passenger	220	65	14300
Fuel (30 gal)	180	55	9900
Total	2070		95360

C.G. = 95360 / 2070 = 46.1 *within limits*

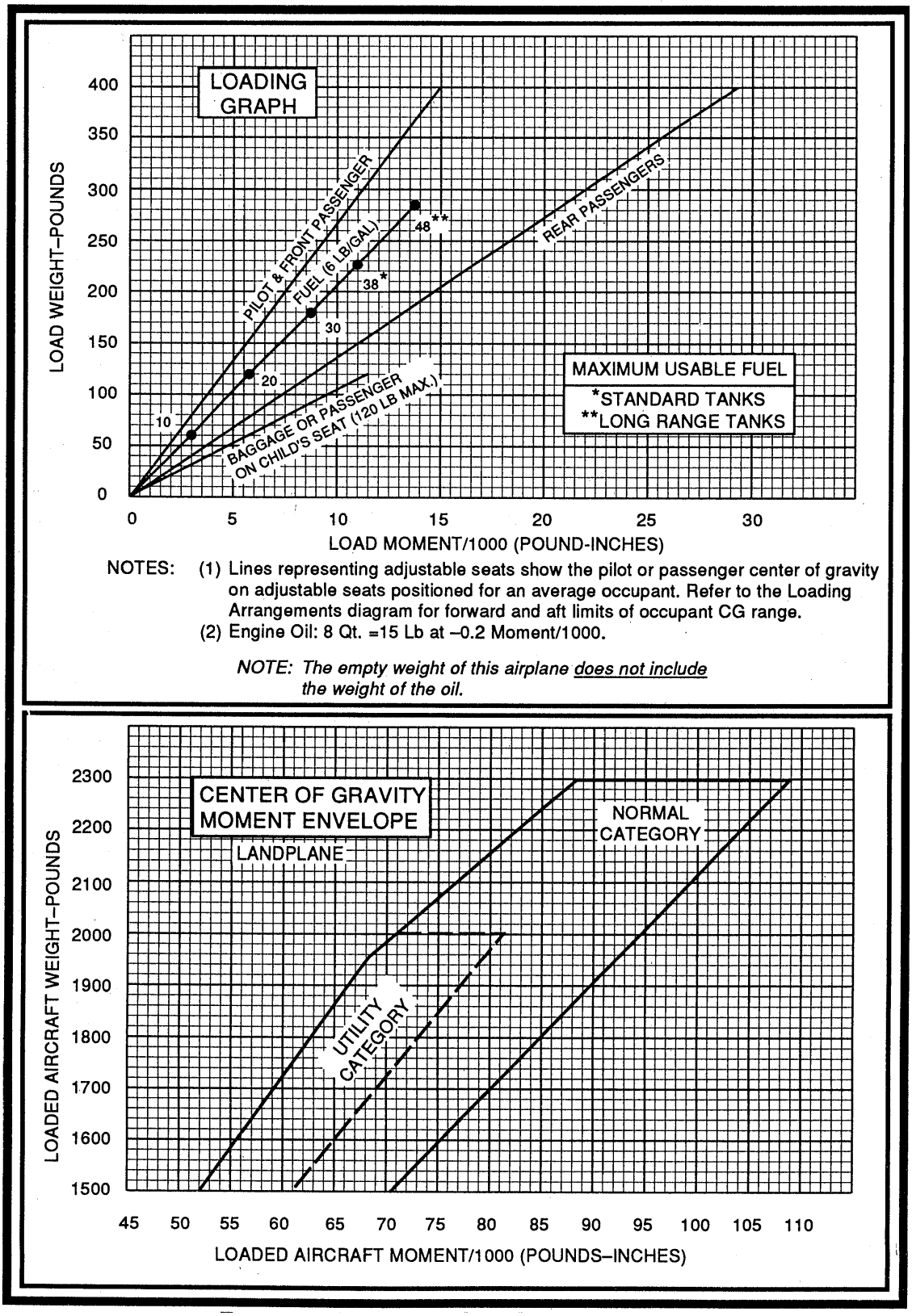
Exercise

Empty weight: 2020 pounds
Empty C.G.: 55 in
Maximum weight: 3600 pounds
C.G. forward limit (all weights): 45 in
C.G. aft limit (all weight): 62 in

Item	Weight	Arm	Moment
Empty weight			
Pilot	190	45	
Front passenger	210	45	
Rear passenger	75	72	
Rear baggage	25	90	
Fuel (60 gal)		55	
Total			

Computing W&B From a Graph

- Computation is the same as the table method above, except the arm is not published explicitly
- For each object, find the intersection of the *load weight* and the *graph line* and then read down to find the moment
- Example: 200 pounds of fuel has a moment of about 10 (which has been divided by 1000)
- Use the C.G. envelope graph to determine if the C.G. is within tolerances

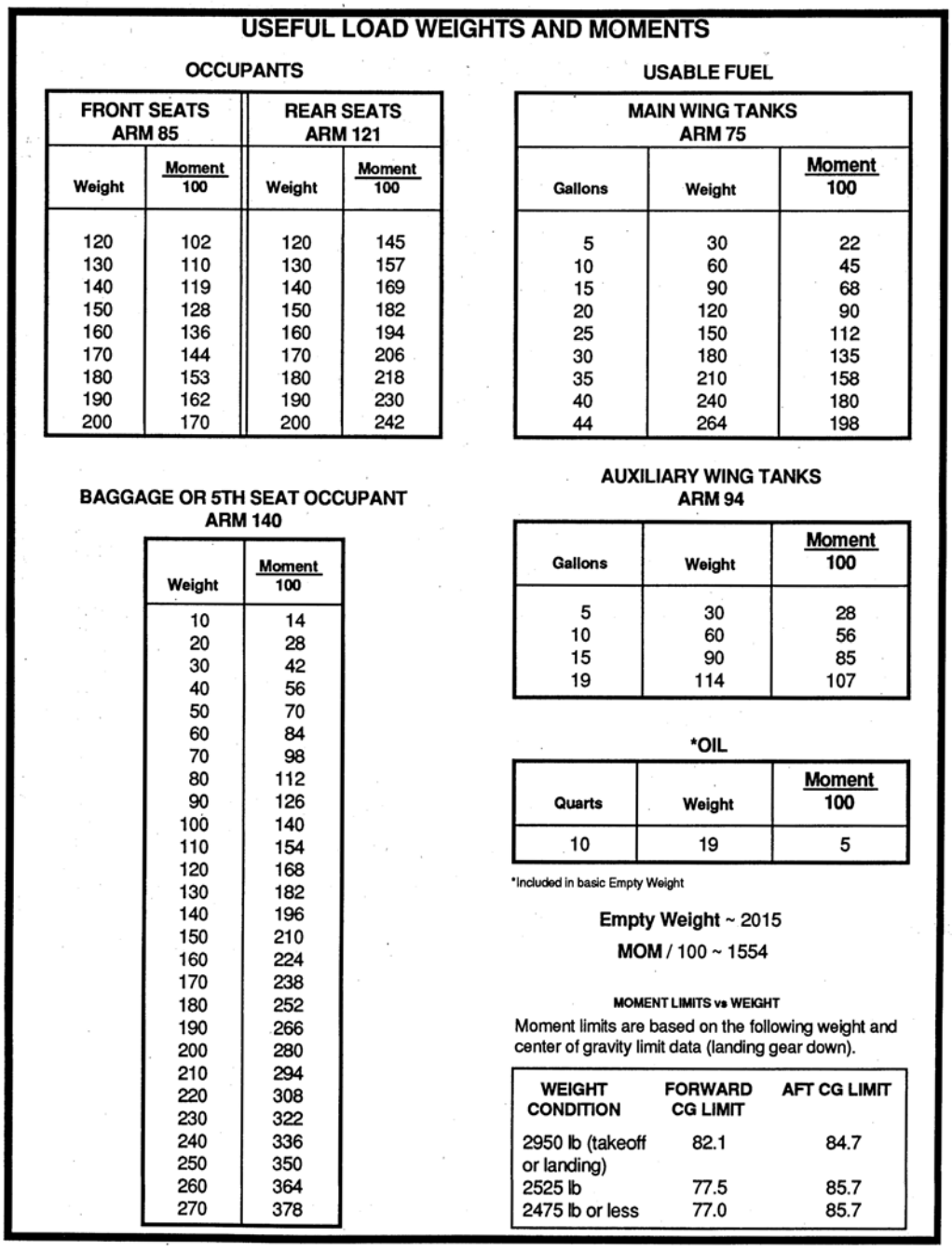


NOTES: (1) Lines representing adjustable seats show the pilot or passenger center of gravity on adjustable seats positioned for an average occupant. Refer to the Loading Arrangements diagram for forward and aft limits of occupant CG range.
(2) Engine Oil: 8 Qt. =15 Lb at –0.2 Moment/1000.

NOTE: The empty weight of this airplane does not include the weight of the oil.

Computing W&B From a Chart

- Computation is the same as the table method above, except the arm is not published explicitly
- For each object, find the relevant entry in the correct table (interpolate between entries if necessary)
- Example: A 155 pound front seat occupant has a moment of 132: (128 + 136) / 2)
- Use the C.G. table to determine if the C.G. is within limits



USEFUL LOAD WEIGHTS AND MOMENTS

OCCUPANTS

FRONT SEATS ARM 85		REAR SEATS ARM 121	
Weight	Moment / 100	Weight	Moment / 100
120	102	120	145
130	110	130	157
140	119	140	169
150	128	150	182
160	136	160	194
170	144	170	206
180	153	180	218
190	162	190	230
200	170	200	242

BAGGAGE OR 5TH SEAT OCCUPANT ARM 140

Weight	Moment / 100
10	14
20	28
30	42
40	56
50	70
60	84
70	98
80	112
90	126
100	140
110	154
120	168
130	182
140	196
150	210
160	224
170	238
180	252
190	266
200	280
210	294
220	308
230	322
240	336
250	350
260	364
270	378

USABLE FUEL

MAIN WING TANKS ARM 75		
Gallons	Weight	Moment / 100
5	30	22
10	60	45
15	90	68
20	120	90
25	150	112
30	180	135
35	210	158
40	240	180
44	264	198

AUXILIARY WING TANKS ARM 94

Gallons	Weight	Moment / 100
5	30	28
10	60	56
15	90	85
19	114	107

***OIL**

Quarts	Weight	Moment / 100
10	19	5

*Included in basic Empty Weight

Empty Weight ~ 2015

MOM / 100 ~ 1554

MOMENT LIMITS vs WEIGHT

Moment limits are based on the following weight and center of gravity limit data (landing gear down).

WEIGHT CONDITION	FORWARD CG LIMIT	AFT CG LIMIT
2950 lb (takeoff or landing)	82.1	84.7
2525 lb	77.5	85.7
2475 lb or less	77.0	85.7

MOMENT LIMITS vs WEIGHT (Continued)

Weight	Minimum Moment 100	Maximum Moment 100
2100	1617	1800
2110	1625	1808
2120	1632	1817
2130	1640	1825
2140	1648	1834
2150	1656	1843
2160	1663	1851
2170	1671	1860
2180	1679	1868
2190	1686	1877
2200	1694	1885
2210	1702	1894
2220	1709	1903
2230	1717	1911
2240	1725	1920
2250	1733	1928
2260	1740	1937
2270	1748	1945
2280	1756	1954
2290	1763	1963
2300	1771	1971
2310	1779	1980
2320	1786	1988
2330	1794	1997
2340	1802	2005
2350	1810	2014
2360	1817	2023
2370	1825	2031
2380	1833	2040
2390	1840	2048
2400	1848	2057
2410	1856	2065
2420	1863	2074
2430	1871	2083
2440	1879	2091
2450	1887	2100
2460	1894	2108
2470	1902	2117
2480	1911	2125
2490	1921	2134
2500	1932	2143
2510	1942	2151
2520	1953	2160
2530	1963	2168
2540	1974	2176
2550	1984	2184
2560	1995	2192
2570	2005	2200
2580	2016	2208
2590	2026	2216

Weight	Minimum Moment 100	Maximum Moment 100
2600	2037	2224
2610	2048	2232
2620	2058	2239
2630	2069	2247
2640	2080	2255
2650	2090	2263
2660	2101	2271
2670	2112	2279
2680	2123	2287
2690	2133	2295
2700	2144	2303
2710	2155	2311
2720	2166	2319
2730	2177	2326
2740	2188	2334
2750	2199	2342
2760	2210	2350
2770	2221	2358
2780	2232	2366
2790	2243	2374
2800	2254	2381
2810	2265	2389
2820	2276	2397
2830	2287	2405
2840	2298	2413
2850	2309	2421
2860	2320	2428
2870	2332	2436
2880	2343	2444
2890	2354	2452
2900	2365	2460
2910	2377	2468
2920	2388	2475
2930	2399	2483
2940	2411	2491
2950	2422	2499

Case Study

Commuter crash raises concerns about weight, balance
Associated Press Jan 22, 2003, 02:31

CHARLOTTE, North Carolina — Flying too close to the known limits for a plane's weight and balance can have catastrophic consequences for a commuter aircraft - as the crash that killed 21 people in Charlotte earlier this month may very well have shown. Investigators have yet to establish the cause of the crash of the US Airways Express flight, which went down at the airport Jan. 8 after taking off at an extremely steep angle. But they are focusing on the possibility that heavy takeoff weight and improper weight distribution combined with a malfunctioning elevator, the tail assembly that controls the plane's pitch, to cause the accident.

The tragedy has focused attention on how the industry calculates the weight of its passengers and cargo. And it has raised questions about whether that method is realistic in this land of expanding waistlines. "I think it's one of the things that may make commuter flying riskier, especially when you're flying with a loaded airplane - the possibility that it could be out of weight or out of (balance) because of variations in the average passenger weight and the distribution of weight," said Jim Burnett, a former chairman of the National Transportation Safety Board.

Among the weight and balance concerns: The plane was full, with 16 men, two women and one child among the 19 passengers. Air Midwest, the airline that operated the turboprop, assumes - with Federal Aviation Administration approval - that passengers flying in winter average 175 pounds each, including clothing and carry-ons.

But given the super-sizing of American waistlines (adult men averaged 180.7 pounds in 1994, the most recent year in which statistics from the Centers for Disease Control and Prevention are available) and the increased size and weight of carry-ons, that standard could have been exceeded on the flight.

Investigators have said the plane's captain and a member of the ground crew debated before takeoff whether the flight was overloaded.

John Goglia, the NTSB member who headed the crash scene investigation, said a ground crew member believed the plane was limited to 26 bags. Goglia said Capt. Katie Leslie decided that all 31 checked bags could remain on board. He said pilots and others interviewed during the investigation thought the plane "looked heavy" as it prepared for takeoff.

Air Midwest assumes - again, with FAA approval - that each piece of checked baggage weighs 25 pounds on average. But some in the industry believe that estimate is too low.

In the Southeast, for example, many travelers bring along their golf clubs, which can weigh well over the estimate. Also, commuter airlines often deliver passengers to big-city airports to catch international flights, for which travelers are likely to pack heavy. (That was not the case with the Charlotte flight, which was headed for Greer, S.C.) It is also believed that many passengers are packing more in their checked luggage these days because carry-ons are so closely screened.

The maximum takeoff weight for the Beech 1900 that crashed in Charlotte is just over 17,000 pounds. The NTSB has said that, according to the plane's documentation at least, it was within 100 pounds of that weight.

As for its weight distribution, Goglia has said that on paper, at least, the plane was within 1 percent of the rearward limit for its center of gravity. (The more luggage that is put in the back of the plane, the farther to the rear moves the plane's center of gravity. Flight rules specify the farthest allowable point.)

Given those conditions, said Paul Czysz, a professor emeritus of aviation and engineering at St. Louis University, a miscalculation could have easily made the plane unbalanced. For example, too many bags in the rear baggage compartment or several heavyset men seated in the rear could have upset the balance.

Czysz and others said that airplane weight limits generally have a built-in safety margin, much like the "empty" line on automobile gas tanks. "You could be 10 percent over the weight limit of an airplane and still fly it," Czysz said.

But the location of a plane's center of gravity is not as forgiving. The FAA says a pilot may not fly a plane if its center of gravity is beyond its forward or aft limit, because such a plane can be uncontrollable once airborne. "It's a very black-and-white thing," Czysz said.

Mary Schiavo, a former inspector general for the U.S. Transportation Department, said margins of error are thin in commuter planes like the 19-passenger Beech 1900.

"The small plane, being so light, you don't have a lot of leeway," said Schiavo, now a Los Angeles-based lawyer who litigates air disaster cases.

Schiavo said calculating an aircraft's weight and center of gravity is so crucial that it is one of the first things prospective pilots learn to do in flight school.

"You don't touch the aircraft until you learn to do weight and balance," she said. "Pilots know that this can make a difference on having a successful flight or not."

A small-plane crash in the Bahamas that killed singer Aaliyah and eight others in 2001 was blamed in part on a plane that was overloaded by at least 700 pounds.

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