Schaufele Annotations
Chapter 10 Weight and Balance

Check on C.G. Location

This exercise is best done using a spreadsheet with a format similar to Figure 10.1 shown here. The spreadsheet will contain many more rows which will include combinations of passenger loading, cargo, and fuel. You may want to use additional columns for c.g. locations (forward location and aft location) and moment arms for determining forward and aft c.g. limits.

Using the OWE values calculated in Chapter 3, calculate the MWE by subtracting the operational items. Two examples are shown in Fig. 10-4 and 10-5, but you should use the weights appropriate to your airplane. As described in the book, the c.g. of the airplane at the MWE condition can be calculated by summing the moments of each group as illustrated in the table shown here. Use Fig. 10-3 to determine the group weights as a function of MWE. For your design, establish a reference point (use the nose of the airplane, or preferably some arbitrary location forward of nose) and find the location of the c.g. of each group with respect to the reference point.

	C.g. location		Group weight	Moment
	Local c.g. location	c.g. location (wrt ref.)		
Wing	0.37 - 0.42 m.a.c.$_{wing}$			
Horizontal tail	0.30 m.a.c.$_{ht}$			
Vertical tail	0.30 m.a.c.$_{ht}$			
Nacelle	0.40 l_{nac}			
Fuselage - canopy type	0.26 l_{fuse}			
Fuselage - cabin type	0.39 l_{fuse}			
Fuselage - airliner	0.45 - 0.5 l_{fuse}			
Landing gear	0.95 l_{gear}			
Equipment	Same as fuselage			
			Σ (weights)	Σ (moments)

Note: l_{gear} is the distance between the nose gear and main landing gear. Ref 10.1, Table 10.2

Fig 10.1 Calculation of Aircraft Center of Gravity at MWE

From this table you can calculate moments and c.g. location. If necessary move the wing so that the c.g. at MWE meets the requirements on page 211, i.e.:

- For engines located on the wing 25% m.a.c.
- For engines located on the aft fuselage 35% m.a.c.

This is an approximate method of wing location. In the exact method, the wing would be moved so that the required c.g. range fits as low as possible into the notch of Fig 6-7 and thus minimizes horizontal tail volume coefficient. You may have to move the wing more than you expect, and it may be better to think in terms of moving the fuselage with respect to the wing. Wing and engines may constitute half the MWE of the airplane, so if the engines are on the wing, the fuselage has to be moved a long way to change the location of the c.g.

If you move the location of the wing, then you <u>should</u>, but you won't have time to do it here, readjust the tail areas to reflect the change in length of the tail arm.

Now inspect Fig. 10-8, and remember that this applies to the DC-9 with engines at the rear. Add the operational weights back in to get to OWE. If engines are mounted on the wing the c.g. travel from MWE to OWE will be small, so you may assume that the OWE is located at the same % m.a.c. as MWE. If the engines are at the rear, the OWE will be forward of the MWE by 3 - 4% m.a.c.

Now add reserve fuel (which you know from your mission calculations). If the engines are on the wing, you can assume reserve fuel is in the outer wing tanks, which may move the c.g. aft about 3 - 4% m.a.c. If the engines are at the rear you will want reserve fuel to move the c.g. as far forward as possible, so assume that reserve fuel is in the inboard tanks. This will take you to the bottom of the first "potato" of the potato plot.

The following steps apply only to Fig. 10-8. Your schedule will probably be different. The DC-9 has five seats per row, with two seats on the left side (looking forward) of the aisle and three on the right. Fig. 10-8 refers to adding cabin crew in addition to passengers. This is not correct. Cabin crew are a component of the operational items (see Fig. 10-4 or 10-5) and were therefore added when adding weight to MWE to reach OWE.

- Fill all the window seats on both side of the airplane for the aft half of the airplane only. This will take you to the right hand side (RHS) of the first potato.
- Now fill the remainder (the forward half) of the window seats. This will now take you to the top of the first potato.
- With all the window seats filled, fill all the aisle seats on the aft half of the airplane only. This will take you to the RHS of the second potato.
- Now fill the remainder of the all the aisle seats. This will take you to the top of the second potato.
- Fill the aft half of the middle seats. Since there is only one middle seat per row on the DC-9, the potato is only half the size of the other two potatoes. This takes you to the RHS of the top potato.
- Fill the remainder of the middle seats. This takes you to the top of the top potato, and the airplane should have all the seats filled.
- Empty all the seats, and then repeat the exercise, this time filling the forward half of the airplane first. This will give you the shape of the left hand side of each potato.

For a 747 with ten seats per row (ABC/DEFG/HJK), fill seats AK first, then HC, then DG, then BJ, then EF (there is no seat "I" so that passengers will not be confused with Row 1 and try to sit in first class). For other airplane configurations, use a similar loading logic. If the engines are located on the wing, the potatoes will stack almost vertically.

All airliners, but not business jets, will have the capability of carrying cargo in the hold under the passenger floor in addition to the passengers' checked bags. Cargo capacity will typically be of the order of 50% of the passenger capacity (see Fig. 15-1) but may be almost 100% of the passenger capacity, as for example the 767-300ER or 767-400ER. When the airplane is operated at less than the design range, cargo revenue is a significant source of income to the airline. Cargo capacity is a function of how many containers (Fig. 5-16) can be fitted into the cargo hold and average container payload density, and is beyond the scope of this exercise. Assume therefore that another 50% of the payload (pax plus baggage) can be carried as cargo.

- From the most adverse passenger aft c.g. loading condition, add cargo from the aft end going forward. This will give you the most adverse aft loading.
- From the most adverse passenger forward c.g. loading condition, add cargo from the forward end going aft. This will give you the most adverse forward loading.

- The addition of cargo weights will bring the weight on the loading diagram up to the end of mission weight (pax plus cargo plus reserve fuel) for a mission operating at the space-limited payload. The space-limited range (Fig. 15-2) is less than the design range.

In practice, the airplane will have loading combinations of fuel and cargo for a constant MTOGW. However, we will assume that no cargo is on board when mission fuel is added. Assume two tanks per side of equal volume. Estimate the total wing fuel tank volume by calculating the volume between the front and rear spars from the side of body to 85% of the span, and then assume fuel occupies 92% of the gross volume. Each side normally has two tanks, inboard and outboard. Assume they are of equal volume. Jet A has a density of about 50.4 lb/ft^3. If the mission fuel does not fit into the wing tanks, the remainder will have to have to go into the center wing box. The c.g. of each tank may be estimated using the following equation taken from Ref 10.2:

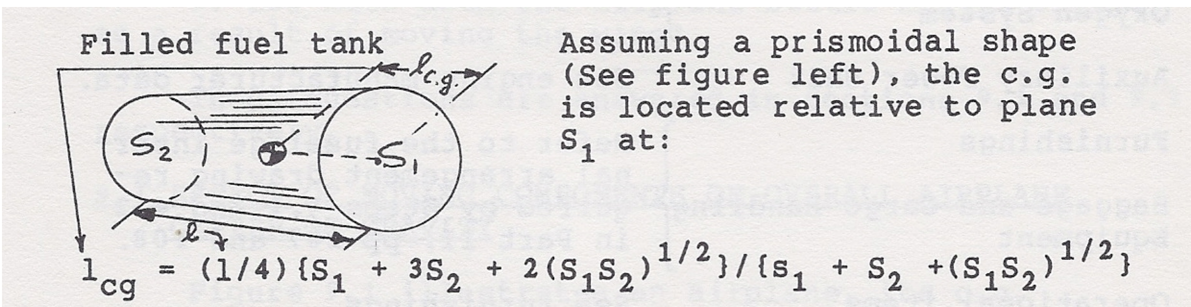

Figure 10.2 Estimate of Fuel Tank Center of Gravity

A more accurate method of estimation of fuel tank volume is given in the annotations to Chapter 15.

- From the top of the top potato, add mission fuel, first to the outer (most aft tanks), then the inner tanks.
- This will bring you up to MTOGW for a configuration operating at the design range.
- Draw an envelope around the c.g. travel that is vertical up to the end of mission weight, then merges to have about a 10% c.g. travel limit at MTOGW.

In practice, airplane loading may be limited to avoid extreme c.g. travel. For example a business jet with aft-mounted engines may have to have bags loaded in the forward baggage compartment first. The pilot is responsible for checking weight and balance (Ref. 10.3).

In addition, aircraft may have slightly different c.g. limits for flight and ground operations. The ground operation aft c.g. limit may be determined by tip-up or by having sufficient load on the nose gear for adequate steering control.

References

10.1 Roskam, J., "Airplane Design Part II: Configuration Design", Roskam Aviation and Engineering Corp, 1985

10.2 Roskam, J., "Airplane Design Part V: Component Weight Estimation", Roskam Aviation and Engineering Corp, 1985

10.3 Anon, "Pilot's Weight and Balance Handbook", Federal Aviation Administration, US Department of Transportation, AC 91-23A, 1977