The Load Adjuster: It Looks Like a Slide Rule, But Is It?

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The Medium is the Message

What leaps out at you and attracts your attention when you first see a Load Adjuster "slide rule" is the graphics: the colored areas on its obverse side and the fuselage diagram of the aircraft for which it was designed on its reverse side. Figure 1 shows three Load Adjusters designed for the B-24 Bomber, the CH-53A Helicopter and the KB-29 Bomber. The slide for the CH-53A has been removed to show the colored weight, index number, and center of gravity (cg) grid that is the basis of the Load Adjuster's design. The obverse side of the slide for the KB-29, with its weight and moment scales is shown, and the reverse side of the slide for the B-24, with its various load scales, is shown. Figure 2 shows the reverse sides of the three Load Adjusters with their fuselage diagrams and load distributions of personnel, bombs, fuel, armaments, and medical evacuation litters.

I referred to the Load Adjuster as a slide rule. The adjusters in the figure certainly look like slide rules, but look more closely. Arguably they're not. Their moveable and fixed scales are not used to perform addition or subtraction of either linear numbers or the logarithms of numbers as is done with slide rules. The scales instead

[1] John Fasal in his book *Nomography* defined a nomogram (or nomograph) as, "..a specific kind of graphical representation of relations of three or more variables in which the numerical values of the variable quantities are represented on functional scales so that any three correlated values of the quantities are located on a straight line."

function like those on a nomograph[1] designed numerically to solve a specific equation. Later in the article, when the Load Adjuster's principle of operation is discussed, this difference will become more apparent.

Weights and Balances

The weight and balance of an aircraft are two of the most important factors affecting the safety of flight. An overweight aircraft or one whose weights are so distributed that its cg is outside allowable limits is both dangerous and inefficient to fly. Different aircraft types have different load requirements. Whereas military aircraft must be highly maneuverable and extremely sturdy, depending upon their mission, transport aircraft must carry large loads of passengers and cargo over great distances at high speeds and minimum costs.

The manufacturer provides the "empty weight" cg (the location along the longitudinal axis of the aircraft where its weight is assumed to be concentrated). The change in the cg at takeoff must be calculated based on the load distribution, taking into account the weight and location of passengers, cargo, fuel, (bombs, armament, missiles, troops and mission-related equipment for military aircraft) and any other changes to the empty weight due to equipment or configuration changes. During a flight, fuel is consumed and its contribution to the total weight decreases. In the case of military aircraft, their weight decreases as bombs and missiles are expended, or after a paratroop jump. These weight changes and the subsequent shift in the cg requires an adjustment of the aircraft's trim to maintain its longitudinal stability in flight. It is the pilot's responsibility to assure that any expected change in the cg during the flight does not exceed the manufacturer's allowable limits.

Although dedicated electronic computers are available today to solve the weight and balance problem, circular and linear slide rules were used in the past (and are used today) to assist the pilot. While the FAA's 1977 edition of its *Pilot's Weight and Balance Handbook* referred to the use of the Load Adjuster, the 1999 edition, retitled *Aircraft Weight and Balance Handbook,* no longer refers to it. Instead, in a separate chapter on the use of computers, the new edition describes the use of electronic calculators and electronic flight computers, as well as the E6-B Flight Computer, a circular slide rule, to solve the weight and balance problem.

The outer fixed and inner movable circular scales of the E-6B Flight Computer or the almost identical MB-4A Computer are used for multiplication and division to solve problems involving speed, distance, and fuel. Since multiplication and division are the primary mathematical operations required for calculating the cg or its shift due to a change in an aircraft's load, these computers can be adapted for this purpose. Pencil and paper nevertheless are still needed to keep track of the computations.

Principle of Operation

The principle of operation of all Load Adjusters is the same, but the specific features of any one model reflect those of the particular aircraft for which it was designed. The reverse side of the Load Adjuster for the CH-53A Helicopter shows the load configurations for its use as a troop transport or a litter carrier. The colored top strip on the obverse side is the guide to a safe loading. The red sections show the limits of the loading range. The change in the position of the transparent slide indicator reflects the change in the cg as the load is increased or decreased in terms of the index scale, that is on the bottom fixed portion of the Load Adjuster. The basic weight and moment scales on the movable slide determine the index starting point based on the aircraft's "empty weight" for all loading calculations.

Although similar in appearance to the conventional linear slide rule, the theory of operation for the Load Adjuster is quite different. Since the conventional slide rule utilizes the principle of addition and subtraction of logarithmic scales to achieve multiplication and division and hence can evaluate many different kinds of mathematical equations, the Load Adjuster can evaluate one specific equation: the equation used for computing the cg of an aircraft as a function of the distribution of its loads. It does this by using nomograph scales to find first the basic index number corresponding to an aircraft's empty weight cg and then finding the subsequent changes to the index number as the aircraft's load changes. The graphical grid on the inside of the slide rule is used to find the corresponding cg as a function of the index number and the aircraft's weight.

The principle of the load adjuster is based on the formula for finding the cg of loads distributed along a beam of negligible weight. Based on a modification to the formula involving scaling, and centering the range of safe operating centers of gravity, the starting basic index number (which is the distance to the location along the longitudinal axis at which the aircraft's empty weight is assumed to be concentrated multiplied by the empty weight) and subsequent changes to it are calculated. The index number formula used for the CH-53A helicopter is:

$$\text{Index Number} = 50 - \text{Weight}\frac{(340 - \text{Center of Gravity})}{20,000}$$

where the constants are unique to the CH-53A helicopter and are chosen for scaling the index number and centering the graphical grid scales. The cg is the distance along the aircraft's longitudinal axis from a datum point in inches and the weight is the total weight in pounds. While the relationship between the weight of an aircraft and its cg is inverse, by choosing fixed values for the cg, a family of linear curves as a function of the index number can be graphed. For a cg value of 335, the preceding formula can be rewritten with weight as a linear function of the index number as follows:

$$\text{Weight} = 200000 - 4000 \times (\text{Index Number})$$

By choosing different values for the cg, the family of curves for the B-24's graphical grid shown in Figure 1 was drawn.

The procedure for using the Load Adjuster is as follows:

1. Find the basic (empty weight) index number by setting the indicator hairline over the "0" index value on the lower outer fixed scale and then moving the slide until the value of the aircraft's empty weight from the "A" or "B" scale is under the indicator's hairline.

2. Move the indicator until the hairline is over the value on the slide's Moment/1000 scale corresponding to the aircraft's empty weight moment. The resulting index value is the basic index value.

3. Repeat the previous steps by utilizing the weight scales for fuel, armaments, personnel, et. al. until the aircraft is fully loaded.

4. Find the cg by using the hairline indicator's position to interpolate the value of the cg along the horizontal axis closest to the horizontal axis value corresponding to the aircraft's loaded weight.

5. Reverse the procedure to find the changes in the cg once the aircraft is in flight and its weight is decreased.

Description, History and All I Know

Two distinguishing features of the Load Adjuster are its use of color on the obverse side to designate the forward and aft safe operating boundaries for an aircraft's cg and the outline drawing of the aircraft's configuration on the reverse side showing its distribution of weights.

The two colors that have been used are yellow, to designate that normal limits have been exceeded or to highlight special notes, and red to indicate that safe limits have been exceeded.

The typical Load Adjuster appears to made of a plastic base to which plastic laminate strips with the appropriate scales and graphics have been glued. Its dimensions are $12\frac{1}{4} \times 1\frac{3}{4} \times \frac{3}{8}$ in.

The Cox & Stevens Aircraft Corporation in Mineola, Long Island, originally developed the Load Adjuster, probably about 1940. The company is believed to have evolved from the eponymous Naval Architecture firm of Cox & Stevens, Inc. Daniel Cox, a principal in both of the firms, was also a president and director of Gibbs & Cox, Inc., the company that designed the liners *SS America* and *United States.*

The earliest reference to the Load Adjuster, that I have been able to locate, appears in *Aerosphere 1939* which lists the Load Adjuster among the various products available from Cox & Stevens. The earliest ad illustrating the Load Adjuster that I was able to locate appeared in *The Aircraft Year Book* for 1943, which also shows several other Cox & Stevens slide-rule-type aircraft computer products. The last mention of the firm in *The Aircraft Year Book* is in the 1945 edition, in which the Load adjuster is referred to as "...the standard weight and balance computer of the Army Air Forces, the Navy, and the British". Sometime, probably in the early 1960s, Cox and Stevens was acquired by the Revere Corporation of America in Wallingford, CT. Load Adjusters from that time on show the Revere Corporation or Revere Transducers as the manufacturer. The Load Adjusters I have seen show either the Cox & Stevens or the Revere names. There is no indication that a patent was ever issued or applied for by Cox & Stevens, although a Load Adjuster designed for the CH-53A Helicopter and manufactured in 1970 displays the registered trademark symbol next to its logo.

The Load Adjuster is still manufactured by the Revere Transducer Division of SI Technologies, in Tustin, CA. The only information I was able to obtain, other than that it was still manufactured, was its current price of $450 with no mention regarding quantity. I was unable to obtain any product literature or a sample of their current models. Revere Transducers may well be the last surviving manufacturer of a linear "slide rule."

The Load Adjuster was produced with a leather case, an identification tag for inserting into a clear plastic pocket on the case, a metal clip for mounting the case to a bulkhead and an instruction pamphlet. About half of the used Load Adjusters I have seen auctioned on e-bay include the original leather cases, usually without mention of the clip or tag. I have rarely seen an instruction pamphlet as part of the offering.

Early models have what may be a serial number engraved at two places. The KB-29 and B-24 adjusters shown in Figure 1 have one on the edge of one end of the slide and the other immediately below on the base. The CH-53A has no serial number. The cases for the KB-29 and B-24 also have what may be serial numbers but which do not correspond to those on the Load Adjusters. Each of the laminated plastic strips designed for a particular aircraft has an identifying number beginning with the letter E. For the B-24 it is E604, for the KB-29 it is E963, and for the CH-53A it is E1180 followed by a dash and a number corresponding to each of the six laminated plastic strips used.

The earliest possible manufacturing date for a Load Adjuster can be estimated from the particular aircraft for which it was designed, based upon the aircraft's first year of flight, its year of entering service, or its production years. The number of Load Adjusters produced can be estimated from the number of aircraft of a particular type that were produced. The Table of Aircraft Types estimates the earliest manufacturing year and the number of Load Adjusters produced for 21 military aircraft models which are in collections or have been advertised on e-Bay. If a Load Adjuster was designed to be used with a number of variants of the original aircraft, only the first model designation is shown in the table. If the aircraft's first year of flight, entering service, or production precedes the first year during which it is estimated that Load Adjusters were produced (assumed to be 1942), the year 1942(cs) is designated as the earliest manufacturing year. If anyone has information on other models, please let me know, so that I can update and publish the table at some future date. You'll find me listed in the membership directory.

A Confession

I was first attracted to the Load Adjuster by its colors and graphics. For me, perhaps it is also its relation to a particular type of aircraft, and hence to aviation history combined with its trompe l'oeil appearance that makes the Load Adjuster an interesting addition to a slide rule collection.

Acknowledgement

The writer thanks Rebecca Looney of the Cradle of Aviation Museum at Mitchell Field on Long Island for her assistance in having made available the museum's collection of aircraft flight computers, and in providing access to the museum's research library with its fascinating trove of original material dealing with the early days of aviation on Long Island.

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Table of Aircraft Types

Model	Description	Earliest Year	# Aircraft
A-26C	Douglas Light Attack Bomber	1944	1,091
AT-11	Beechcraft Bomber Trainer	≈1944	???
B-17G	Boeing Flying Fortress Bomber	1943	8,680
B-24D	Consolidated Liberator Bomber	1942(cs)	18,475
B-25C	North American Medium Bomber	1942(cs)	9,889
B-26	Martin Marauder Bomber	1942(cs)	5157
KB-29	Boeing Superfortress Bomber[1]	1942	3,970
B-36D	Convair Consolidated Bomber	1950	86
B-47E	Boeing Strategic Medium Bomber	1954	≈1,000
B-50A	Boeing Superfortress[2] Bomber	1948	280
B-52G/H	Boeing Strato Fortress Bomber	1961	295
C118A	Douglas Transport	1946	167
C-119	Fairchild Flying Boxcar Transport	1947	≈1,000
C-130	Lockheed Hercules Cargo Transport	1956	231
C-46	Curtiss-Wright Commando Transport	1942	≈3,000
C-47/RD4	Douglas Light Military Transport	1942(cs)	10,926
CG-4A	WACO, Troop-carrying Glider[3]	1942(cs)	≈20,000
CH-53A	Sikorsky Sea Stallion Heavy Lift Helicopter	1965	141
KC-135A	Boeing Strato Tanker	1956	732
OA-10	Consolidated Catalina Patrol Flying Boat	1942	380
PB-4Y	Consolidated Privateer Patrol Flying Boat[4]	1942(cs)	739

1. The KB-29 was the tanker version of the B-29 bomber. The reverse face of the KB-29 Load Adjuster, shown in Figure 2 is, for reasons unknown, that of the bomber.
2. The Superfortress designated both the B-29 and the B-50.
3. Cessna, Ford, and nine other companies also produced the CG-4A.
4. The same Load Adjuster is used for the B-24 and PB-4Y. In the PB-4Y version, the wing was located over the B-24 fuselage.

But you should also know that it's valuable when you want to get two or three significant answers to a problem, especially when no calculator is handy. The other file is some documentation. Attached FilesÂ I guesss one may look silly figuring out their MPG on a slide rule though. I still use mine since the "back side" has some convenient SI->IMP scales. Does it do Hex to binary conversions? I lost my Hex slide rule. #4 Like Reply. Jan 28, 2011 #5. That Ductulator looks like a nomogram, yet another anacronistic thing we don't use much anymore. But if it slides, I guess it is a sliding nomogram. In the field and in harsh environments, slide rules and nomograms still find use. I was a volunteer fireman. I made nomograms to help calculate pressures and flows for the pump engine. Coated in plastic, it could still be used in the wet at -40 degrees. Feb 7, 2015. #8.