The Maya erected ~~his~~ a vaults in four principal members - two walls first, and then two half-vaults which, above the cap-stone, merge into on mass, which we have been calling the roof cap, or cap. He did not bind the base of his half vaults to the walls, but he hid the essential disconection of his two half vaults by this connected masonry through the cap. It will be readily agreed that the dead weight of the front half of this cap rests on the front half-vault, the rear half on the rear halfpvault. Each half vault plus its cap therefore acts as a separte unit so far as the downward forces of gravity are concerned. ~~We will try to show later that where~~ There will be a slight tendency of the cap to ~~bed~~ bend of its own weight in the middle between the tops of the soffit slopes, but the gap is so short that we may disregard this. We will try show that no other forces than compression, from each side toward the center, will be brought to bear on this cap unless something else moves. We are thus justified in theoretically cutting this cap vertically over the center of the room, and treating each half vault and its ~~cap~~ half cap as a member of the structure. The half-vaults of which we talk will have the form of Fig   including the cap. In figuring the weight, we will also include the roofing concrete on each half-vault as part of it, but since this had little or no strength, we will not consider it a structural member of the building, but a dead load which the latter must support. On the other hand we assume, at first, that each member is infinitely strong so that none of the forces involved can change its shape or volume - that is, stretch it or crush it.

Let us examine two or three cross sections of half-vaults, apart from their walls. In Fig ~~xx thexleftxhandxportionxisxreally xxcontinuationxofxthexwall~~ the center of gravity is between d and s. We may consider that all the weight acts through the center of gravity c; and since the wall is infinitely strong, it will meet an equal and opposite reacting force from the wall at ~~d~~e, and this is the condition of equilibrium, since there are no moment arms to create rotational movement . The forces meet head-on . Further, this unit is to a certain extent in stable equilibrium. If it is tipped to the left (rotated about c) the center of gravity will move up as well as to the left. Unless the movement goes too far, as soon as the tipping force is released, gravity will pull the unit back into place. The same is true for a tipping about s as an axis, though to a less extent.

The degree of resistance to such tipping forces is equalized for either direction in Fig 2 , which is a balanced double half vault used over ~~in~~ the inner halves of two paraellel rooms . It will be clear without further comment that either of these forms can be ~~placedxon~~ built up on independently on the walls indicated, and combined to form as many ranges of rooms as is desired; two of form one for a single range, and these combined with one of form two for each additional range desired. So long as internal deforming stress in the walls are considered, each half vault and its supporting wall will be independently stable, and sol of course, will they be stable when combined.

In form 3 (Fig. 3) the half-vault is even more more stable so far as resistance to rotating arounf point d is concerned, but what is gained for this direction is lost for the other. The slightest push to the right will send it over, as the center of gravity on this rotating immediately begings to descend.

In figure 4 the center of gravity is out beyong point s and the half vault will obviously rotate of itself about point s (at least until it slips off) as in Fig. 5. It is clear that we can prevent this rotation by applying a suitable horizontal force F1 as shown in Fig . Let us suppose we are dealing with a model, and the wall is set on a board floating in a tube of water. If we keep up our force F1, (which we assume is just enough to prevent the rotation) the half vault will not tip, but the whole thing will move across the tube. If we fix wall to the table, and eliminate friction between the bottom of the half vault it will simply slip across the top of the wall, as in Fig To prevent its doing so we would have to provide a force to the right, F2 in Fig. , which we will make just sufficient for the task, and no more. Now F2 must exactly equal F 1 for equilibrium. This is because we arre here dealing only with the the prevention of a movement of translation, the whole mass moving from one position to another. We long ago stopped any movement up or down by balancing the weight through c with the equal and opposite reaction froce through s. We must similarly balance F1 to the left with F2 to the right, in an equal amount and opposite direction. If F2 were greater than F-2 the half-vault would be pushed off to the right; if less, it would continue to the left, though at a slower rate.

In a Maya building there is plenty of friction between the vault and the top of the wall, and it is the wall, acting through this friction, that supplies the counter thrust force F-2. So long as there is equilibrium, the force F-2, headed outward, is transmitted through the cap and half vault to the wall, and the wall reacts with an equal force directed inward, just asthe ~~floor~~ wall reacts with a vertical upward reaction against the weight at s.

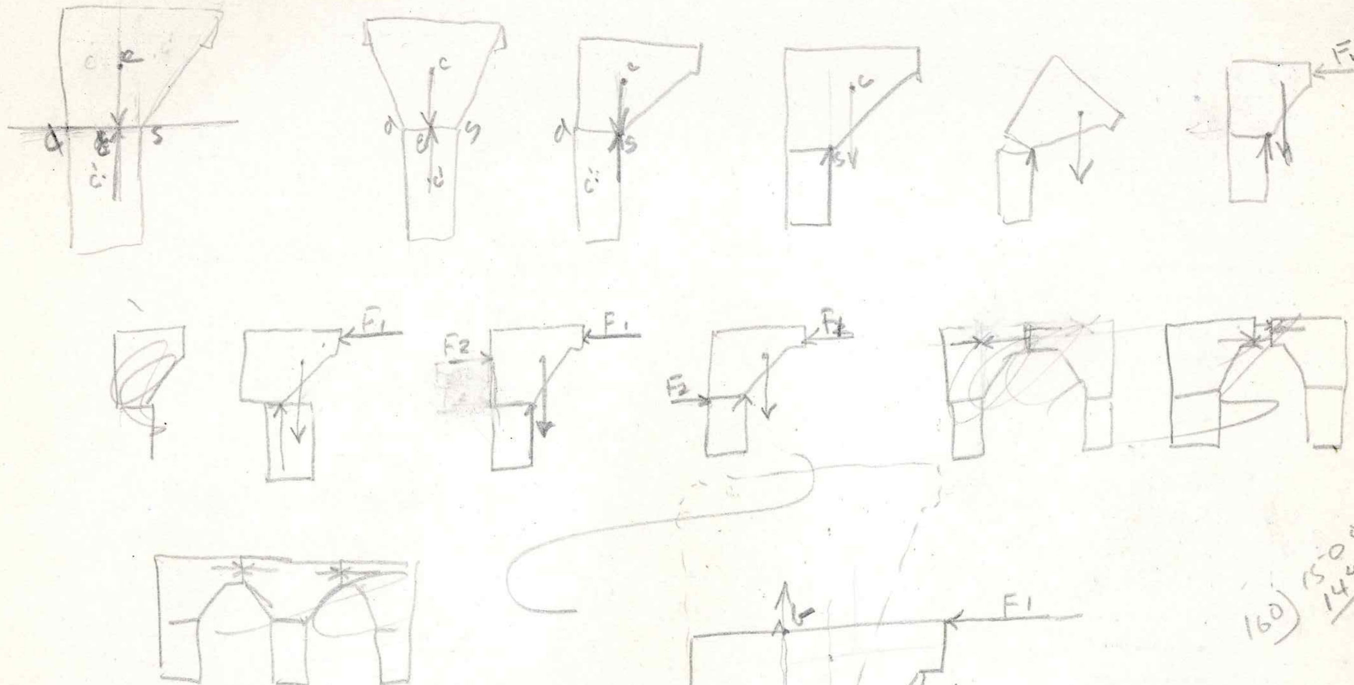
Now we know that F-1, which we had to supply (from the other half-vault in a real building) to keep our half-vault from rotating, exactly equals F2. Further that F-1 is exactly enough (and no more) to prevent the rotation of Fig , by assumpti

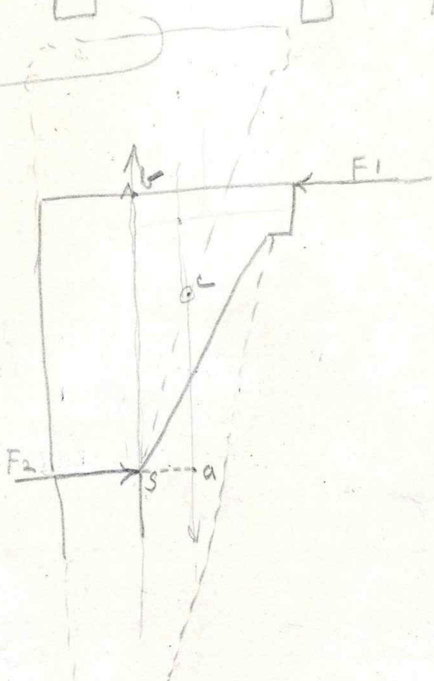
But we do not know the amount of F-1 as yet, and since it varies for different vault forms we must work it out, and must beging by going back to the force which made it necessary - the rotational force or moment ~~xxxx~~ which seeks to cause the turning around an axis at s, the spring of the vault.

Fig   is the same vault form at a larger scale. The threatened tipping is a motion of rotation about the vault spring as an axis (s) and therefor involves a force acting on a lever or moment arm, which is the perpendicular distance from the line of action of the force to the axis of rotation. The force is the half-vault weight acting through the vertical line through the center of gravity c. The perpendicular diatance to it is the line sa. The measureme of a rotational force is a moment, in this case w (the weight) times sa the moment arm. F-1 is a rotational force in equal amount - that is of the same moment, but its lever arm, the perpendicular distance from its line of action (ob) to the axis (s) (~~ab~~ is much longer). Therefor the force is much less. ~~If~~ The section of vault we are considering ~~is~~ (has a base of .60 m and a span of 1.00 (one half the width of the room, the cap slope being disregarded.) (Its area is (at our scale) 79.2 cm. Let the section be) cut to a thickness giving it a weight of ~~1000~~ (792 lbs, or 10 lbs to a square cm.), and the line sa measures ~~15~~ .35 cms., the moment of the weight about s is ~~15 x 1000 or 15000 Lb cms.~~ (.35 x 792 lbs or 277.2 Lb cms.) ~~If sb~~ The (moment arm of the counter-thrust equals 9.9 cms.) ~~measures 160 cms~~ the moment of F1 about s is ~~160 x 1000 or 160000 Lb cms.~~ (9.9 x F-1.)

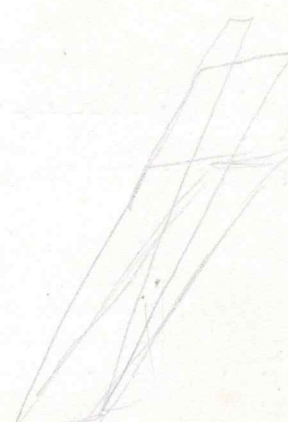
Since the two moments are equalm(one just balances the other) (9.9 F-1) ~~160 F-1~~ equals (2772.00 and F-1 = 277.20 divided by 9.9 or 28 lbs.) ~~15000 and F-1 equals 83.7~~ Lbs. This is the force which would have to be distributed over a length of vault equal to the thickness of the cut section which gave us the actual weight of 792 ~~1000~~ lbs.

Insert A — Now if we ~~change~~ ~~decrease~~ increase the soffit slope (and consequently the vault height, but keep eberything else constant, the value of F-1 (which as we have seen must equal the thrust to be met by F-2) will decrease. This is indicated by broken lines in the Figure. While the moment arm s-a is the same, the weight is greater, and the moment or rotational force to be counteracted is greater. But the momnet arm of F-2 has so lengthened as to more than make up for this. The calcuatation will now be . Thus it is seen that while a steep vault for a given span and wall is heavier, it introduces less side thrust and is more nearly stable. TRial with ~~various slopes will show that~~ (given) ~~if the~~ upper facade slopes, (that is, either positive or negative battered,) both the weight and its moment arm increase, but the combined effect does not equal the advantage of the moment arm or leverage of F-2. ~~Only when the slope~~





160) 15000 (93.7
1440
600
480
1200



That is to say, whether the upper facade is vertical or has a given slope, for a given span ~~the~~ (offsets and cap-stone exposure remaining the same, of course) a steep soffit slope will reduce the side thrust, though it will increase the downward component or weight.

Therefore

2. After erection, the <u>direction</u> of the resultant of the equal amount of thrust in Lbs., when comibined with the greater downward force of the weight, in pounds, will be changed by the difference in the relation of the moment or lever arm~~s~~ of the one to the other, and as we shall see, this will be favorable to the stability of the wall, and impose a lesser strain on it, internally.

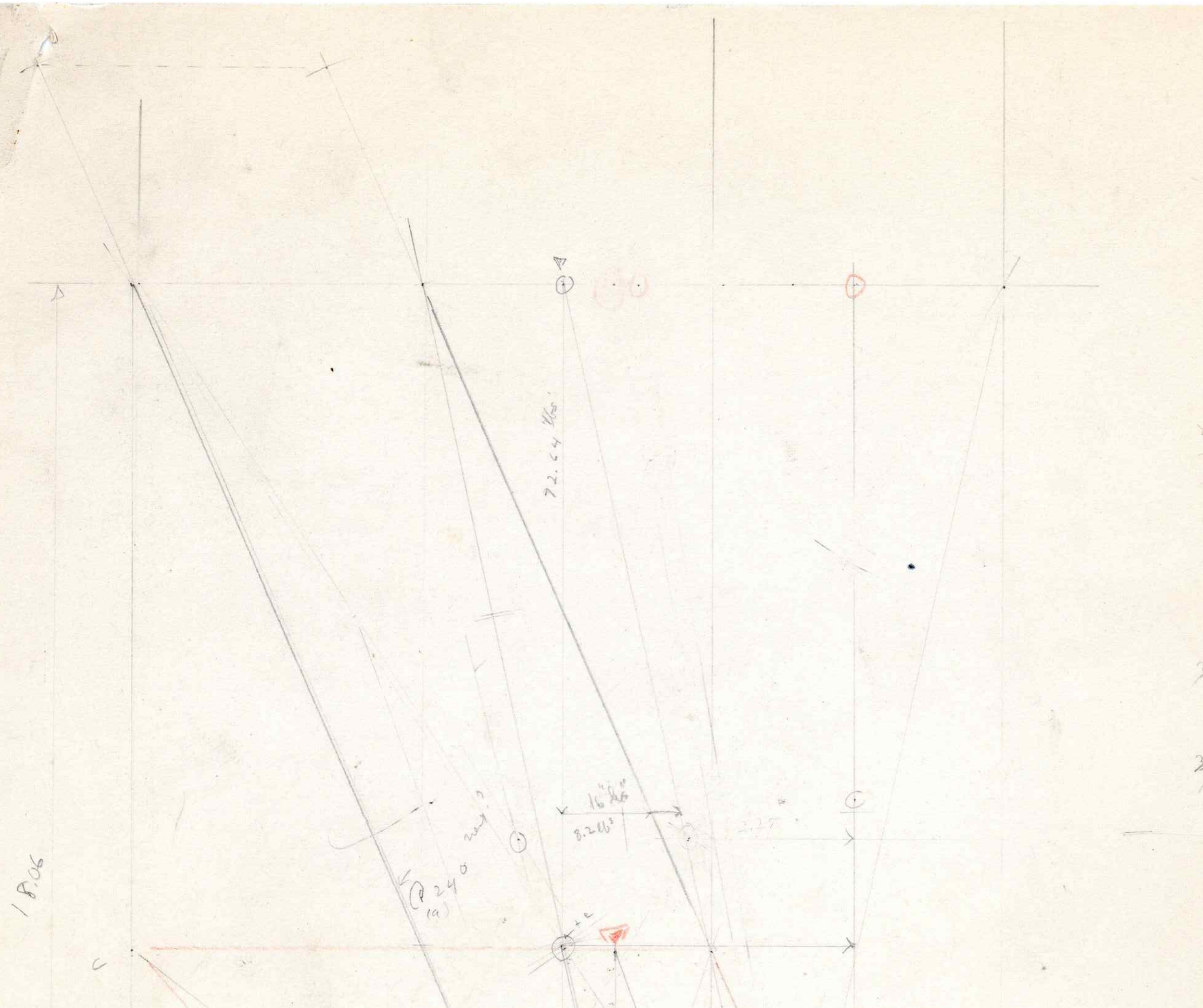
Now suppose the change in the soffit slope is applied to a half-vault with a positively baterred upper facade. Both the weight and its moment arm will be increased. Notwithstanding this the moment arm of the counter-thrust will be so increased as to compensate for this

Now if we increase the soffit slope ~~kx~~ 31 degress from the vertica[l] we will incre ase the moment arm of the counter thrust to 13.8 cms., but the weight to 1104 Lbs. The moment arm of the thrust (produced by th[e] weight of the half vault) will remain the same. That is, the new center of grabity of the half vault will be directly over the former. Working these out we will find the amount of counter thrust in Lbs. we will find it ~~again~~ the same, 28 Lbs. That is, 1104 Lbs. times .35 cms equals ~~3864.00~~ 386.40 Lb-cms ~~5520 Lbs.-cms.~~, and this, divided by the new moment of the counter-thrust, 13.8, still equals 28 Lbs. Increasing the slope to 24 degress from the vertical gives the same result. The firty-degree slope with which we started is a very flat hypothetical soffit, the other two slopes which are known, approximately at Piedras Negras. The spread is a wide one, and we may conclude that raising the soffit slope, <u>with</u> a vertical upper facade, does not ~~xnaxxxxaxkhax~~ ~~affect~~ the amount of side thrust, that is the counter thrust which must equal it, in Lbs. per lineal measure of the the vault. We should note two things however:

Before the counter thrust has been applied, the tendency to the rotate about point s has increased as as the increasing weight, times the same moment arm (sa) has increased. That is, the steeper slope calls for more outside support while it is being erected.

Trial with a positively batterred upper facade will show that both the weight and its moment arm~~s~~ increase, but the longer moment arm of the counter-thrust ~~(Fx2)~~ will still more than compensate. With a negatively batterred upper facade, as the soffit slope is raised, the weight only increases. The moment arm of the weight is lessened and that of the counter thrust is inceased. In any case theh, raising the soffit slope will decrease the actual number of pounds of thrust, per unit length of vault. ~~B~~

C₁



18.06
9.05
9.01

24°

a/ am c = ~~2.25~~ 4.0 ✓

area ov 18.6 × 4

a+b 36.20
.40
18.02
ov → 54.62
Stobb → 18.02
72.64 ✓

9.05

a+b = 9.05 × 4 = 36.20

c 9.01 × 4 = 36.04

d 9.01 × 4
2) 36.04 (18.02

9.01 × 4 = 2) 36.04

d cam = 2.95 × 8

area ov 23.60

2) 23.60 (11.80

1.10

11.80
15.10
26.90 ✓

2.05
5.75
1025
1435
1025
2) 11.7875 (5.8937

9.21
5.89
15.10

5.75 × 8
2) 46.10 23
15

c// cam = 2.29

8 1.95

2.05

2) 7.15 (3.56

2) 9.3 (4.65
13
12
10

4.06
1.95
2.05

2) 4.5 (2.25

3) 13.05 (4.35
12
10
10

3) 13.5 (4.5
15
15

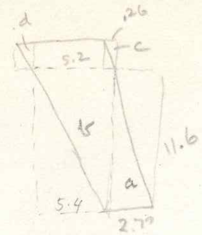
3) 2.6 (8.66
24
20
18
20

3) 5.22 (1.93

3) 13.7 (4.6

Sloping

@ ~~28~~ 40°



Over hang area.

b = 31.32
c = 4.16

d = .16
c = .08

35.72

Slobbone. 20.66

v. weight 56.38 (called Kilos).

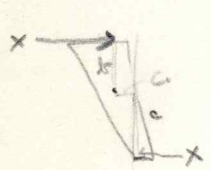
1 cm = 1 Kilo.

Diagonal ▭ is 12.4 = 56.38 Kilos

1 cm = 12.4) 56.380 (4.54+
496
678
620
580
496

Torque ~~Thrust~~ (▭) meas 1.48 (Kilos.
4.54 (per cm)
1.48
3632
1816
454
5.7192

Trq = 5.71 Kilos.



bx = 5.71 Kilos

b measures 5.5

5.5x = 5.71 Kilos

x = 5.5) 5.71 (1.038
55
210
165
450
440

c x' = 5.71

c measures 6.90

6.9x' = 5.71

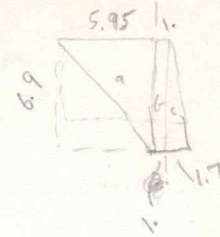
x' = 6.90) 5.710 (.82+
5520
1900

145
-82
63

145) 630 (4.3+% decrease in thrust.
580
500

5-11 front room

@ 40°



Overhang a 5.95
6.9
5355
3570
2) 41.055 (20.52+

Slobb. b = 6.9×1 = 6.90

c = 6.9
1.7
483
69
2) 11.73 (5.86

33.33 = vault weight.

6.90
2.91
3.99

Diag (v.h) = 6.9 = 33.33 Kilos (our scale).

1 cm = 6.9) 33.330 (4.830
276
573
552
210
207
30

Torque ▭ meas. 1.2 ; 4.83
1.2
966
483
5.796 (Torque).

bx = 5.79

b meas 2.91

2.91x = 5.796

x = 2.91) 5.7960 (1.99
291
2886
2619
2670
2619

cx' = 5.796

c measures 3.99

3.99x' = 5.796

x' = 3.99) 5.7960 (1.45
399
1806
1596
2100
1995

145) 820 (1.55+% increase in thrust
725
950
870

For edge of wall

a w = 72.24
cam = 2.05
36120
144480
148.09220

18.06) 148.092 (8.2
14448
3612
3612
1806
1625

checks with vector.

c w = 53.88
1.3
16164
5388
70.044

8.98) 70.044 (7.8
6286
7184
7184

checks with vector

d w = 38.67
cam. .98
30936
34803
37.8966

5.75) 37.8966 (6.5+
3450
3396
2875
5216

checks with vector

a 8.2 F
c 7.8 F
d 6.5 F

On each axis, F are to each other as C arms are to each other.

?

For center

a F = 16 (other sheet) - checks on vector △.

c 53.88
3.29
48492
10776
16164
177.2652

8.98) 177.26 (19.8 ±
898
8746
7982
7640
7184
456

checks with △ vector. ±!

d w = 38.67
2.95
19335
34803
7734
113.2765

5.75) 113.076 (19.6+
575
5557
5175
3826
3450

checks in △ (±)

Probably.

a = 16 ← facade over room.
c = 19.8 ← facade to inner wall.
d = 19.6 ← facade over wall.

Does change ~~cease after~~ begin only as facade goes over room?

+ compare with above

See Sheet C

.07764 mm = 72.64 lbs
.01 mm =
1 cm = 10 lbs
1 m = 1 lb
16 m = 16 lbs
72 m = 72

a

w = 72.64
cam = 4
290.56

F = 18.06) 290.560 (16.08+ (=16.09)
1806
10996
10836
16000
14448
1552

a/ w = 72.24
cam = 4
288.96

F = 18.06) 288.96 (16.+
1806
10836
10836

d

w = 26.90
cam = 2.95
13450
24210
5380
79.3550

F = 5.75) 79.355 (1
575
2185

d/ w = 38.67
2.95
19335
34803
7734
103.0765

F = 5.75) 103.076 (17.9+
575
4557
4025
5320
5175

c

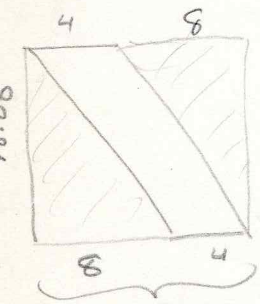
w = 53.88
cam = 2.29
48492
10776
10776
123.3852

F × 8.98 = 123

F = 8.98) 123.38 (13.7+
898
3358
2694
6640
6286

F for
a = 16.08 16.
c = ~~13.7~~ 19.8
d = 17.9

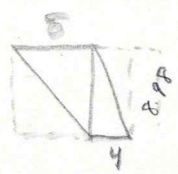
area of a



18.06
12
3612
1806
216.72
144.48
72.24

less 18.06
8
w 144.48

area c

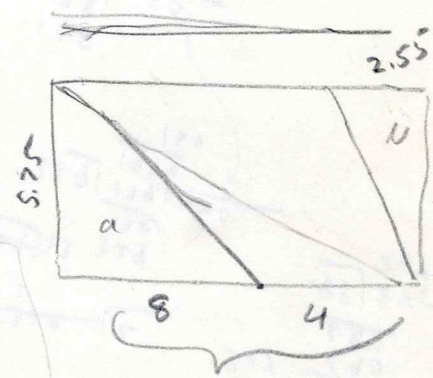


8.98
4
2) 35.92 L 17.96

8.98
8
2) 71.84

35.92
53.88

area d



5.75
12
1150
575
69.00
- 30.33
w = 38.17

less 5.75
8
2) 46.00 L

b: 5.75
2.55
2875
2875
1150
2) 14.6625

23.000
7.3312
30.3312

Mount wall Middle

a	2.05	4.10	= 2/1	4.10/2.05	4.10
c	1.30	3.29	2.5/1		
d	.98	2.95	3/1	3.29/1.30	

130)329(2.5
260
690
650
329

.98)295(3
294

130)329(2
2

329)13 329
130
329)199.0(.60
1974
160

8.2
2
164

7.8
2.5
390
156
1970+

6.5
3
19.5

19.8
7.8
19.8)12.00(.60
1188
12

Sec B

a   weight = 740.

am = 2.05

370.0   81.5+   E-2

14800

18.6 | 1517.00

1488

29.00

186

1040

930

quarter than in lbs.
But direct am is
still better.

c   weight = 690.

1.21

690

1380

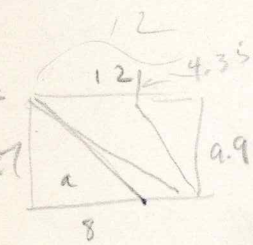
690.   8

9.9 | 834.90

792

4299

c w =



E. w. = 576.7.

1.21

5767

11534

5767

9.9 | 697.807   60.4+

693

480

396

84

9.9 × 12 = 19.8, 99, total 118.88

61.13

57.67

a = 9.9 × 8 = 2 | 79.2 | 39.6

b = 9.9 × 4.35 = 495, 297, 396, 2 | 43.065 | 21.53

21.53

39.60

61.13

3.21
2.5

Increasing span with vertical zone.

Rule 25% - Sheet A. (cp) See over

a Overhang = 7.44
stab arc = 7.44
total area 14.88

a Moment w = .35

14.88
× .35
7440
4464
Moment = 5.2080

F-1 need = 18.6) 5.208 (.28 (+)
372
1488
1488
000

a Overhang = 3.96
stab = 3.96
7.92

7.92
.35
3960
2376
9.9) 2.772 (.028
198
792
792

7.92
.35
2.7720
2.772 0

9.9) 2.77.2 (28.
198
792
792

Note ~~Moment~~ Steeber s/½ = same thrust in lbs; but better angle.

b Overhang. overhang: 110.4
× .35
5520
3312
13.8) 38.640 (2.80
276
1104
1104

1104
.35
13.8) 38.640 (2.80
276
1104
1104

If span is increased, we had other change:
In vertical other zone, ~~in~~ no change in lbs of thrust
(about big change in counter thrust moment arm.