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WEIGHT ESTIMATION FOR AIRPLANES WITH OTHER ALLOYs AND MATERIALs

MOHAMMAD AZADIAN[1], SAYYED BASIR AJELLE[2], SAEED RASHIDI[3], SHAYAN DEHKHODA [4]
1-Amirkabir university of technology (polytechnic),Tehran, Enghelab street,betwin pole colledge and Valie asre street

Abstract
The reduction of weight is an important issue that all of designers have a noticeable focus on that .In this paper we have determined the effect of other alloys in airplanes structure as one of the most effective ways of reducing the airplanes weight.The most focused thing in here is that ,witch part of airplane is going to be made by other alloys .For example if we use composite in wing of a80.66 ton transport jet instead of AL ,the reduction of weight would make its weight about 75.9 ton . other syntaxes are calculate as the result. But we can not calculate these numbers for all airplanes . so all of the results of weight reductions are calculated for a 80.66 ton transport jet that is designed for bringing about 186 passengers to the range of 4000 km. since this kind of airplane is one of the most produced number in transport jets(for example A320),it can give a good preview to the designers of these kind of airplane, to select the type of alloy and the type of syntax that this alloy would be used. But the speed of calculations in the first step of airplane design is important ,too.so we our method of calculating is as short as it can be.

Keywords: *Alloy-Composite-Syntax-weight reduction*

Introduction
In recent years the using of some new alloys like AL/LI or using new materials like composite is going to be the first select of designers to reduce the Wight of the air plane . all of these attempts are because of reduction of fuel . because as more as we reduce he structural weight of the airplane ,we will reduce the weight of mission used fuel too, and it will be the Couse of saving money that many of airliners are interested in.so there is a wide vision of designers in using new and light materials.In this paper we have used a simple method for estimating the reduction weight of an airplane that is going to change its materials to better ones.

Calculations:
The estimated weight for a 186 pax transport jet is about 80.66 ton (calculated from ref1) was for afull ALUMINUM structural air plane.

WEIGHT COMPONENTS
Before the calculation of the amount of the reduction due to the new material using , we have to know that any part of the airplane has which fraction of airplanes W_{TO}(maximum take off weight)AND W_E(empty weight).To reach this goal ,we use the (reference 2):
To know that any component of air plane has what per cent of the $\mathbf{W_{TO}}$ we should use the nearest group of airplanes to our air plane in appendix **A** at the end of the reference 2 . then we will use the average of these planes components fractions to the W_{TO}.
Here we do the same way for our air plane like example2.2.2 of reference 2 :
our weight values for this airplane were determined as a result of the preliminary sizing performed in ref1.
These weight values are summarized as following

W_{TO}	80.66 ton−177855.3lb
W_E	42.934 ton=94669.47lb
W_{Pay}	18.135 ton=39987.675lb
W_F	18.3098 ton−40.373109lb
W_{crew}	0.877 ton−1933.785lb
W_{tfo}	0.4033 ton−889.2765lb

Table 1: weight values calculated from ref1 methode

It will be assumed that GW=W_{TO} for this airplane .This is consistent with the data in Tables A7.1 through A7.5 from ref 2.
For easy reference the airplane will be referred to as the Ourania,(the name of the Greek Muse of Astronomy .
STEP 2: Tables A7.1 through A7.5 of ref 2 contain component weight data for airplanes in the same category as the Ourania .Specifically the following airplanes have been comparable sizes and missions McDonnell-Douglas DC-9-30 and MD-80, Boieng 737-200 and 727-100.
STEP 3: For reasons of brevity , only the following component weights are considered:
Wing,Empennage,Fuselage,Nacelles,Landing Gear, Power Plant, Fixed Eqpmt
STEP 4: The following table lists the pertinent weight fractions and their averaged values. Because the intend is to apply conventional metal construction methods to the Ourania , there is no reason to alter the average weight fraction.

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	McDonnell-Douglas DC-9-30	MD-80	Boeing 737-200	727-100	Ourania Average
Pwr Plt/GW	0.076	0.079	0.071	0.078	0.076
Fix Eqp/GW	0.175	0.182	0.129	0.133	0.155
Empty Wht/GW	0.538	0.564	0.521	0.552	0.544
Wing Grp/GW	0.106	0.111	0.092	0.111	0.105
Emp. Grp/GW	0.026	0.024	0.024	0.026	0.025
Fus. Grp/GW	0.103	0.115	0.105	0.111	0.109
Nac. Grp/GW	0.013	0.015	0.012	0.024	0.016
Gear Grp/GW	0.039	0.038	0.038	0.045	0.040

Table 2:fraction of each component to GW for our same mission airplanes

Note that the ratio of the W_E/GW witch fallows from the preliminary sizing, is :94669.47/177855.3lb=0.532.This is almost close to the average value of 0.544 in the above tabulation.

STEP 5: Using the averaged weight fraction just determined , the following preliminary component weight summary can be determined:

Component	First weight estimate lbs	Adjustment lbs	Ourania Class I weight (alum.) lbs	Class I weight (li/alum.) lbs
Wing	13,335	+329	13,664	12,298
Empennage	3,175	+ 78	3,253	2,928
Fuselage	13,843	+341	14,184	12,766
Nacelles	2,032	+ 50	2,082	1,874
Landing Gear	5,080	+125	5,205	5,205
Power Plant	9,652	+239	9,891	9,891
Fixed Eqp.	19,685	+486	20,171	20,171
Empty Wht	66,802	+1,648	68,450	65,133
Payload			30,750	30,750
Crew			1,025	1,025
Fuel			25,850	25,850
Trapped fuel and oil			925	925
Take-off Gross Weight			127,000	123,683

Table 3: the example of reference 2

But if we combine these two tables(2,3) we will reach the following table for our airplane with W_{TO}=80.66 ton , our weight components would be as folluowing table:

	W/Wto	W/We	First weight estimate	Adjustment	Waccurate
PWR	0.076	0.139706	6.1332	0.073948	6.207148
FIX EQP	0.155	0.284926	12.5085	0.15082	12.65932
EMTY Weight	0.544	1	43.9008	0.52931	44.43011
WING	0.105	0.193015	8.4735	0.102165	8.575665
EMP	0.025	0.045956	2.0175	0.024325	2.041825
FUS	0.109	0.200368	8.7963	0.106057	8.902357
NAC	0.016	0.029412	1.2912	0.015568	1.306768
GEAR	0.04	0.073529	3.228	0.03892	3.26692
sum			42.4482	0.5118	42.96

Table 4: OUR WEIGHT COMPONENTS

Litium/Aluminium (LI/AL) ALLOY

As it is shown in table 9 using of li/al will decrease the ammunt of wing ,empennage,fuselage,nacelles about 10 percent . so we will do the same way.

But as reference 1s says , (page 18 of reference 1),when we want to calculate the effect of using other materials instead of Aluminium in an airplanes structure , we have to change the $W_{E\ ALLOW}$ that have been calculated from equation 2.16 in reference 1.

So first we have to know the decrease of allowable value of W_E ($W_{E\ ALLOW}$) to reach this goal.

If we multiply the w/we fraction (from table 4), by the per cent of the components weight decrease(ten percent for lial) we will reach the reduction of $W_{E\ ALLOW}$ that we call $W_{EALLOW\ ACCURATED}$.

For example for finding the per cent of decreasing $W_{E\ ALLOW}$ by using the li/al instead of AL in the **wing structure** we will have the fallowing way:**Reduction per cent of $W_{EALLOW}=(W/W_E)\times 0.1=$0.019301**

Other reduction per cents for using li/al instead of Al are as following:

	Reduction per cent of $W_{E\ ALLOW}$
WING	0.019301
EMP	0.004596
FUS	0.020037
NAC	0.002941
sum	0.046875

Table 5:Reduction per cent of $W_{E\ ALLOW}$

But its important to know that the reduction of **$W_{E\ ALLOW}$**doe to the using of al/li instead of ALUMINUM is not executed in the weight of Other components as power plant or landing gear.

The note is that we can use the li/al in the airplane in several methods. For example we can use this alloy in wings structure alone or We can use it in wing and fuselage together (wing +fuse).Hence when we design a li/al (wing+fus) , the reduction will be:

Reduction per cent of $W_{E\ ALLOW}$ = reduction per cent of $W_{E\ ALLOW}$ by using li/al wing+ reduction per cent of $W_{E\ ALLOW}$ by using li/al fuselage

Hence :

Reduction per cent of $W_{E\ ALLOW}$ =0.019301+0.020037=0.039338

Hence the **reduction per cent** of other syntaxes are as following:

wing+ EM	wing+ FUS	wing+ NAC	WING+ EMP+FUS	WING+ EMP+NAC	WING+ FUS+NAC	EMP+ FUS+NAC	EMP+ FUS	EMP+ NAC	FUS+ NAC
0.023897	0.039338	0.022243	0.043934	0.026838	0.042279	0.027574	0.024632	0.007537	0.022978

Table 6:The reduction per cent of other syntaxes

By using this reduction per cents we can find the reduced **$W_{E\ ALLOW}$** (**$W_{EALLOW\ ACCURATED}$**) due to use the li/al instead of AL in related method of using the alloy.

NOTE:An example of reduction in using full AL/li(full = Wing +Empennage +Fuselage +Nacelle) is as following:

Reduction per cent of $W_{E\ ALLOW}$= 0.046875

So when we guess a W_{TO} , the $W_{E\ ALLOW}$ that is calculated from equation 2.16 has to be decreased about 0.046 per cent and after reduction of this W_E

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ALLOW , the reduced $W_{E\ ALLOW}$ has to be equal to W_E that is calculated from fuel fraction method .

Hence : $W_{E(ALLOW)\ after\ using\ AL/LIALLOY}$ (for full li/AL) $=(1-0.046)\times W_{E(ALLOW)}$

After trial and error we will reach the amount of 73.43 ton for W_{TO} that it will result $W_{E(ALLOW)Full\ Aluminium\ structured}$=39.21844 ton and this amount will result $W_{E(ALLOW)\ after\ using\ AL/LIALLOY}$ =37.38007 ton from above equation, that is nearly equal to W_E from fuel fraction method=**37.38224**ton (by just 2 kg error) .

Here we have calculated the reduction in each method of the using of LI/AL instead of AL in the structure:

	W_{TO}	W_F	W_E from fuel fraction method	$W_{E(ALLOW)}$ after using AL/LI ALLOY	$W_{E(ALLOW)}$ Full Aluminium structured
WTO(FULL LI/AL)	73.43	16.66861	37.38224	37.38007	39.21844
WTO(wing li/al)	77.52	17.59704	40.52336	40.52266	41.32018
WTO(EMP li/al)	79.89	18.13503	42.34352	42.3407	42.53617
WTO (FUS li/al)	77.4	17.5698	40.4312	40.43189	41.25857
WTO(NAC li/al)	80.17	18.19859	42.55856	42.55422	42.67975
WTO(WING+EM li/al)	76.8	17.4336	39.9704	39.9719	40.95049
WTO(WING+FUS li/al)	74.5	16.9115	38.204	38.20426	39.76869
WTO(WING+NAC)	77.05	17.49035	40.1624	40.16515	41.07887
WTO(WING+EMP+FUS)	73.84	16.76168	37.69712	37.69703	39.42932
WTO(WING+EM+NAC)	76.34	17.32918	39.61712	39.62155	40.71424
WTO(WING+FUS+NAC)	74.1	16.8207	37.8968	37.89034	39.56302
WTO(EM+FUS+NAC)	76.23	17.30421	39.53264	39.53664	40.65774
WTO(EM+FUS)	76.7	17.4109	39.8936	39.89171	40.89914
WTO(EM+NAC)	79.4	18.0238	41.9672	41.96618	42.28488
WTO(FUS+NAC)	76.95	17.46765	40.0856	40.08479	41.02752

Table 7:The reduced W_{TO} in each method of using the LI/AL instead of AL

COMPOSITE :

Composite is an other selection of modern airplane designers that is daily developing in all machines .Here if we use the composite instead of ALUMINUM , we can use the component fractions found in last part but some of other component fractions must be found.

For finding the ratio of surface controls to W_E we can take the same way of finding the ratios of past components .so we use the table A7.2b of reference 2 in the same way.

The ratios that have been taken from the table A7.2A AND A7.2B are as following:

	boing 737-200	727-100	747-100	Airbus A300-B2	AVERAGE
SURFACE CONTOLLER/FIXED	0.15772	0.14078	0.11077	0.165692	0.14374
FURNISHING/FIXED	0.446278	0.481979	0.590609	0.37546	0.47375

Table 8

So ratios of surface controllers and furnishings to W_E would be:

$$\frac{WEIGHT\ OF\ SURFACE\ CONTOLLER}{W_E} = \frac{WEIGHT\ OF\ SUR}{W\ \text{I}}$$

(1)

$$\frac{WEIGHT\ OF\ FURNISHING}{W_E} = \frac{WEIGHT\ OF\ FURNISHING}{W\ \ FIXED} \times \frac{W\ \ FIXED}{W_E} = 0.134932$$

Table A7.2a Group Weight Data for Jet Transports

Type	Boeing 737-200	727-100	747-100	Airbus A-300 B2
Number of engines:	2	3	4	2
Weight Item, lbs				
Wing Group	10,613	17,764	86,402	44,131
Empennage Group	2,718	4,133	11,850	5,941
Fuselage Group	12,108	17,681	71,845	35,820
Nacelle Group	1,392	3,870	10,031	7,039
Land. Gear Group	4,354	7,211	31,427	13,611
Nose Gear				
Main Gear				
Structure Total	31,185	50,659	211,555	106,542
Engines	6,217	9,325	34,120	16,825
Exhaust and Thrust-Reverser System	1,007	1,744	6,452	4,001
Air Induct. System	0	0	0	0
Fuel System	575	1,143	2,322	1,257
Propulsion Install.	378	250	802	814
Power Plant Total	8,177	12,462	43,696	22,897
Avionics + Instrum.	625	756	1,909	377
Surface Controls	2,348	2,906	6,982	5,808
Hydraulic System / Pneumatic System	873	1,418	4,471	3,701
Electrical System	1,066	2,142	5,348	4,923
Electronics	956	1,591	4,429	1,726
APU	836	60	1,130	983
Air Cond. System* / Anti-icing System	1,416	1,976	3,969	3,642
Furnishings	6,643	10,257	37,245	13,161
Miscellaneous	124	85	-421	732
Fixed Equipm't Total	14,887	21,281	63,062	35,053
$W_{oil} + W_{tfo}$	not			known
Max. Fuel Capacity	34,718	48,353	331,675	76,512
Max. Payload	34,790	29,700	140,000	69,865

*Includes pressurization system

Table A7.2b Group Weight Data for Jet Transports

Type	Boeing 737-200	727-100	747-100	Airbus A300-B2
Flight Design Gross Weight, GW, lbs	115,500	160,000	710,000	302,000
Structure/GW	0.270	0.317	0.298	0.353
Power Plant/GW	0.071	0.078	0.062	0.076
Fixed Equipm't/GW	0.129	0.133	0.089	0.116
Empty Weight/GW	0.521	0.552	0.498	0.559
Wing Group/GW	0.092	0.111	0.122	0.146
Empenn. Group/GW	0.024	0.026	0.017	0.020
Fuselage Group/GW	0.105	0.111	0.101	0.119
Nacelle Group/GW	0.012	0.024	0.014	0.023
Land. Gear Group/GW	0.038	0.045	0.044	0.045
Take-off Gross Wht. W_{TO}, lbs	115,500	160,000	710,000	302,000
Empty Weight. W_E, lbs	60,210	88,300	353,398	168,805
Wing Group/S, psf	10.8	10.4	15.7	15.8
Emp. Grp/S_{emp}, psf	4.9	5.6	5.2	4.8
Ultimate Load Factor, g's	3.75*	3.75*	3.75*	3.75*
Surface Areas, ft^2				
Wing, S	980	1,700	5,500	2,799
Horiz. Tail, S_h	321	376	1,470	748
Vert. Tail, S_v	233	356	830	487
Empenn. Area, S_{emp}	554	732	2,300	1,235

*Assumed

Table 9:the information's of table A7.1 and A7.2 of reference 2

NOTE:FROM NOW WE NAME THE SURFACE CONTROLLERS (FLAPS, SLATS, ACCES PANELS, FAIRINGS)AS SURFACE.

We have to multiply the fractions of components of table 4 and table 8 by the (1-fraction) of the table 2.16 amounts in reference 1:

Weight Reduction Data for Composite Construction

Structural Component	W_{comp}/W_{metal}
Primary Structure	
Fuselage	0.85
Wing, Vertical Tail,	
Canard or Horizontal Tail	0.75
Landing Gear	0.88
Secondary Structure	
Flaps, Slats, Access Panels,	
Fairings	0.60
Interior Furnishings	0.50
Air Induction System	0.70 - 0.80

Table 9

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So the reduction per cent of W_E would be as following:

COMPOSITE COMPONENT	PERCENT OF REDUCTION OF W_E
FUSE	0.030055
WING+EMP	0.059743
LANDING GEAR	0.008823
FLAPS, SLATS, ACCES PANELS, FAIRINGS(SURFACE)	0.016382
INTERIOR FURNISHING	0.06746
SUM	0.182463

Table 10: PERCENT OF REDUCTION OF W_E for eachcomposite component

Hence if we use composite for these components the entire reduction of W_e would be about **18** per cent .

Note :**for finding the components weight fraction we have used the same way that have been used in last part for LI/AL alloy**.
If we use the composite instead of Aluminium the reduction fractions are as fallowing:

METHOD	W_{TO}	W_t	We	W_E (ALLOW) AFTER USING COMPOSITE	$W_{E(ALLOW)}$ Full Aluminium structured
WTO(FULL COMPOSITE)	58.03	13.17281	25.55504	25.5592	31.26367
FUSE	75.9	17.2293	39.2792	39.27133	40.48821
WING+EMP	71.65	16.26455	36.0152	36.01412	38.30241
landing gear	79.2	17.9784	41.8136	41.81009	42.18229
FLAPS, SLATS, ACCES PANELS, FAIRINGS(SURFACE)	78.01	17.70827	40.89968	40.89067	41.5717
INTERIOR FURNISHING	70.	16.03	35.221	35.22	37.77
fus+wing+EMP	67.8	15.390	33.058	33.056	36.318
FUSE+LANDING GEAR	74.5	16.922	38.212	38.247	39.794
FUSE+SURFACE	73.5	16.684	37.436	37.431	39.254
FUSE+INTERIOR FURNISHING	66.8	15.177	32.336	32.338	35.833
FUSE+WING+EMP+LANDING GEAR	66.7	15.147	32.236	32.238	35.756
FUSE+WING+EMP+SURFACE	65.8	14.952	31.576	31.571	35.321
FUSE+WING+EMP+INTERIOR FURNISHING	60.4	13.713	27.382	27.387	32.497
WING+EMP+LANDING GEAR	70.4	15.996	35.116	35.114	37.699
WING+EMP+SURFACE	69.5	15.776	34.364	34.363	37.194
WING+EMP+INTERRIOR FURNISHING	63.5	14.414	29.756	29.7599	34.097
WING+EMP+LANDING GEAR+SURFACE	68.4	15.529	33.526	33.520	36.632
WING+EMP+LANDING GEAR+INTERIOR FURNISHING	62.5	14.205	29.049	29.047	33.621
WING+EMP+SURFACE+INTERIOR FURNISHING	61.8	14.030	28.458	28.452	33.222
WING+EMP+LANDING GEAR+SURFACE+INTERIOR FURNISHINGS	60.9	13.824	27.759	27.759	32.751
LANDING GEAR+SURFACE	76.5	17.383	39.801	39.808	40.837
LANDING GEAR+INTERIOR FURNISHING	69.4	15.774	34.356	34.352	37.189
LANDING GEAR+SURFACE+INTERIOR FURNISHING	67.4	32.789	15.311	32.7889	36.137
SURFACE, INTERIOR FURNISHING	68.5	15.554	33.61136	33.61	36.6805

Table 11: the reduction of W_{TO} in each method of using the composite instead of AL.

The diagram of mission fuel fraction of some types are as following:

For full Composite AIRPLANE:

Region	Region - Name	$\frac{W_{i+1}}{W_i}$	W_i (ton)	W_{i+1} (ton)	Expended Fuel (ton)
1	Engine Start & Warm Up	$\frac{W_1}{W_{TO}} = 0.995$	58.03	57.73985	0.29015
2	Taxi	$\frac{W_2}{W_1} = 0.99$	57.73985	57.16245	0.577399
3	Take-off	$\frac{W_3}{W_2}$ 0.995	57.16245	56.87664	0.285812
4	Climb	$\frac{W_4}{W_3} = 0.97$	56.87664	55.17034	1.706299
5	Cruise	$\frac{W_5}{W_4} = 0.867$	55.17034	47.83268	7.337655
6	Loiter	$\frac{W_6}{W_5} = 0.985$	47.83268	47.11519	0.71749
7	Decent	$\frac{W_7}{W_6}$ 0.99	47.11519	46.64404	0.471152
8	Fly To Alternate & Decent	$\frac{W_8}{W_7} = 0.974$	46.64404	45.4313	1.212745
9	Landing , Taxi & Shut down	$\frac{W_9}{W_8} = 0.992$	45.4313	45.06785	0.36345

Table 12:Full Composite AIRPLANE calculated informations

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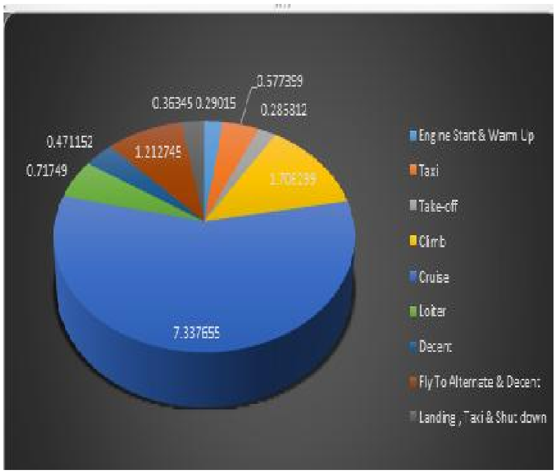

Figure 1:fuel fraction diagram of full composite airplane

For fullLI/AL AIRPLANE:

Region	Region Name	$\frac{W_{i+1}}{W_i}$	W_i (ton)	W_{i+1} (ton)	Expended Fuel (ton)
1	Engine Start & Warm Up	$\frac{W_1}{W_{T.O.}} - 0.995$	73.4	73.033	0.367
2	Taxi	$\frac{W_2}{W_1} - 0.99$	73.033	72.30267	0.73033
3	Take-off	$\frac{W_3}{W_2} - 0.995$	72.30267	71.94116	0.361513
4	Climb	$\frac{W_4}{W_3} - 0.97$	71.94116	69.78292	2.158235
5	Cruise	$\frac{W_5}{W_4} - 0.067$	69.78292	60.50179	9.281129
6	Loiter	$\frac{W_6}{W_5} - 0.985$	60.50179	59.59427	0.907527
7	Decent	$\frac{W_7}{W_6} - 0.99$	59.59427	58.99832	0.595943
8	Fly To Alternate & Decent	$\frac{W_8}{W_7} - 0.974$	58.99832	57.46437	1.533956
9	Landing , Taxi & Shut down	$\frac{W_9}{W_8} - 0.992$	57.46437	57.00465	0.459715

Table 13: Full LI/AL AIRPLANE calculated informations

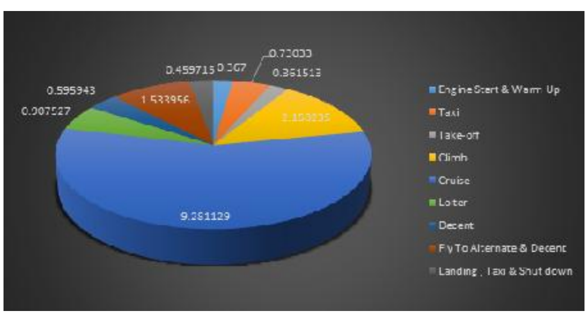

Figure 2:fuel fraction diagram of full LI/AL airplane

Result :

In the first steps of design the speed of calculations is an important problem and this paper provides a wide view for the designers those want to know the effect of changing the material of airplanes structure rapidly. For example the designer of a transport jet similar to our selected transport jet can decide that by changing the wing from AL to composite and the fuselage from AL to LI/AL alloy how lighter weight airplane it can result. So this paper can give good wide view to this kind of problems.

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