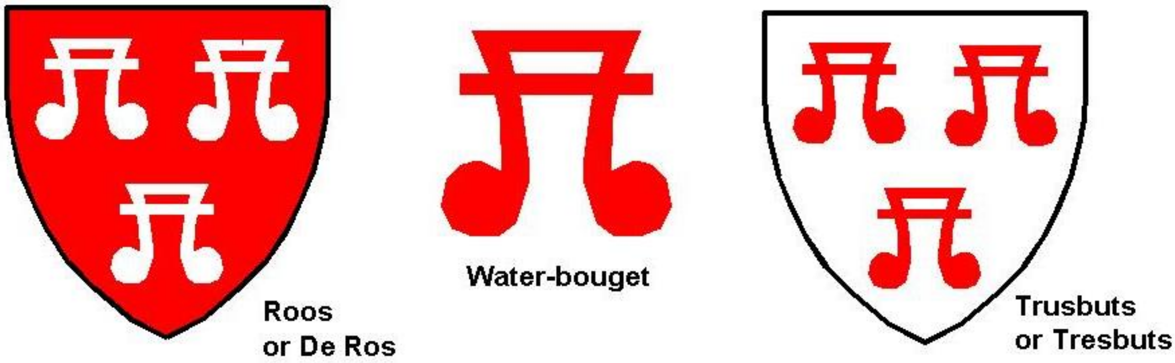
BUDGETS

THE WORD BUDGET

Budget: *noun* an estimate of revenue and expenditure
verb estimate cost and make provision for it.

Originally, in medieval times, a Budget was a pouch, or wallet usually made of leather. It is still shown in heraldry (stylized) as a water-bouget (a pair of leather carriers mounted on a yoke so they can be carried across the shoulder).



Of course another thing a budget would carry is money. In the 17th century the word also came to mean the contents of the bag (i.e. money) as well as the bag itself. In the 18th century the word was used as the informal title for the annual statement on the nation's finances in Parliament and from then the word has moved in general use for estimates on financial positions.

In engineering the term is not only used for money, but any quantifiable and limited resource in the system that requires monitoring.

WHAT IS A BUDGET?

A budget is a breakdown of the utilisation of a quantifiable resource.

Key features of a budget:

- normally an estimate of the future
- balances incomings with outgoings
- details individual components.

Budgets are the potentially key method to derive, monitor and control of quantitative requirements on the system.

So what should be budgeted, the answer is any (and all) quantifiable resources - once budgeting is appreciated an industry tends to embrace the technique.

e.g. on a spacecraft budgets are maintained for

mass	power	propellant/fuel
pointing errors	RF link	telemetry/data

and, ironically, the one engineers tend to forget – money

But other things that could be budgeted (although not on spacecraft) include:

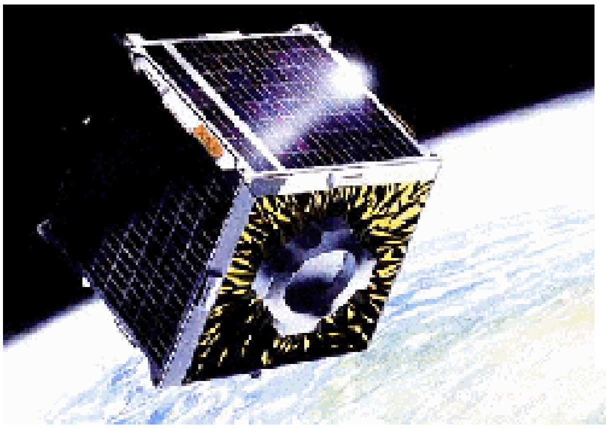
space (rack, floor)	water
bandwidth	time

WHY DO BUDGETS?

The use of budgets in the requirement generation and system level design are used to establish key interface parameters.

For example the power budget establishes the size of the power generation system. The water supply budget sizes the delivery pipeline. The fuel budget determines the size of the fuel tank.

In the later lifecycle phases the continued maintenance of budgets can be a key tool to maintain insight into the status of a system during its development. Because it monitors interface parameters it quickly highlights that problems exist and where they are (but not what they are). They act as a fire alarm network that connects the system level team into the lower levels.



EXAMPLE - BUS-Alpha

A small satellite project for undergraduate students in the Aerospace Department. Designed to be launched on an Ariane 4 as a secondary payload.

BUS-Alpha BUDGETS

ITEM	MASS (kg)	POWER (watts)	DATA (bits/frame)
Experiment	3.0	1.5	256
Structure	4.5	0	-
LV Interface	0.5	0	-
Data Handling	1.2	0.3	64
Power Supply	1.5	0.8	256
Attitude Sensing	1.6	0.3	192
Radiation Monitoring	1.1	0.3	256
Radio Transmitter	2.2	5.0	-
Solar Power Panels	4.5	-	-
Batteries	1.8	-	-
Total	21.9	8.2	1024
Margin	2.1	1.8	-
Allowable	24.0	10.0	1024

MARGINS

Margins are the differences between the estimated total of a budget and the total resource available to the system. Establishing margins and then monitoring their level is a key way to manage uncertainties during all the systems lifecycle phases.

If, when built, the system mass is 19 kg and the system allocation is 20 kg you have a margin of 1 kg (result happiness).

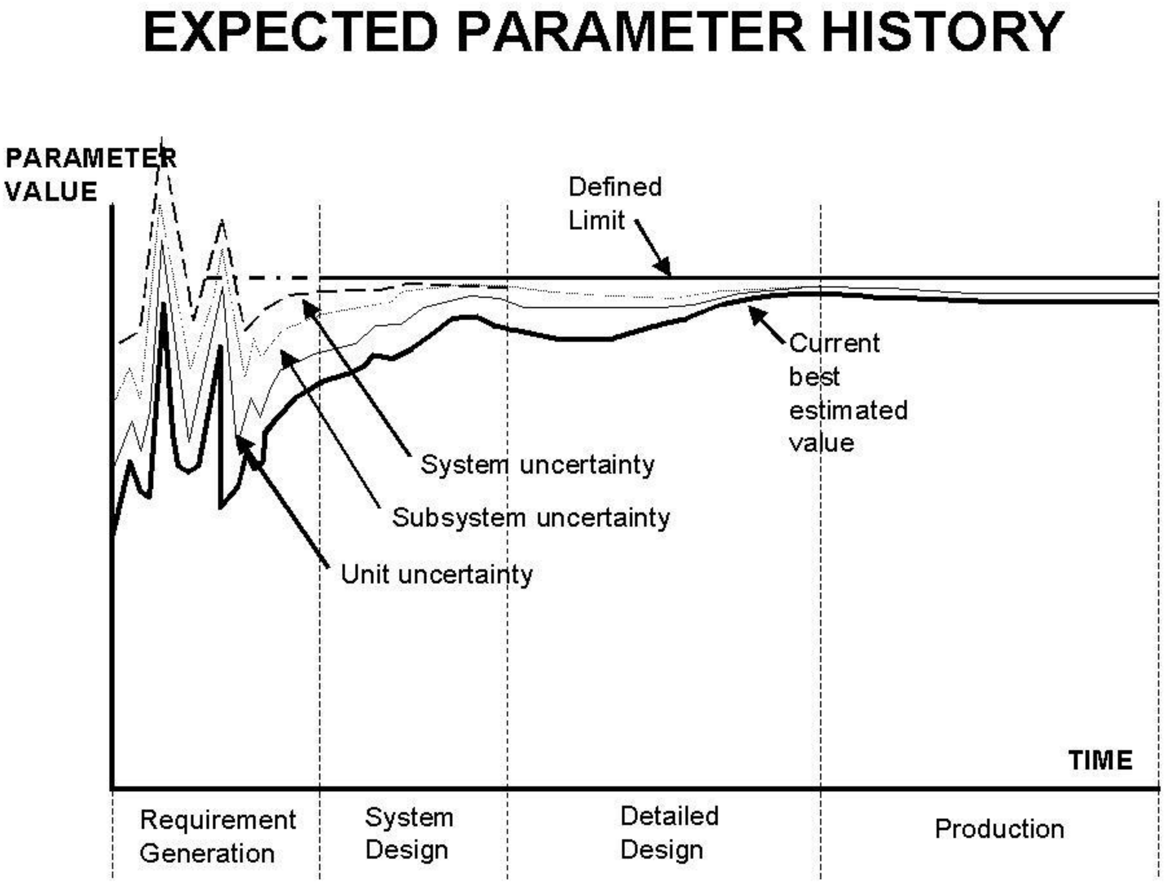
If, when built, the system mass is 21 kg and the system allocation is 20kg you have a margin of 1 kg (result misery).

(with apologies to Dickens)

The trick is to have sufficient margin during the development and production phases to cover uncertainties in the design and build, but not to have grossly oversized the allocations.

No estimate of the actual situation in the future is going to be accurate. This is especially true at the start of a project, which is precisely when the information would be of most use. Commitment to specifications and design features is made at this time (requirement generation and system design phases) before the system has even been designed in detail let alone built and tested.

It is therefore important to be able to allocate margins that cover the uncertainty in the budget. However these cannot generally be too great because this can affect the competitiveness of the system and in some case bring in to question the feasibility of the system. Margins should accurately reflect the uncertainty.



WHO HOLDS THE MARGIN?

Ideally the estimates should come from the specialist engineering departments for the bits of the system they produce and should be pure estimates, with an assessment of the probable error.

In practice many engineers will have a hidden margin in their estimates to the system engineering team.

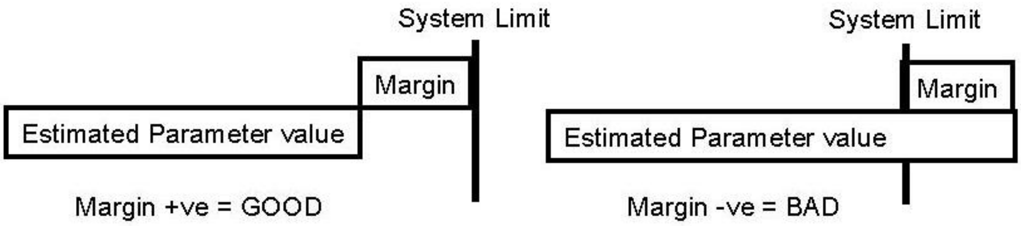
This can even be institutionalised (e.g. authorised use of funny density values which include a margin).

This use of hidden margins is not good practice as nobody ends up with a good overview of what the system status actually is. But if engineers are to be persuaded to give up hidden margins they have got to be given adequate open margins. Further once these margins are agreed the system engineering team should treat them as frozen and beyond further question.

Margins are a measure of risk. Tight margins mean high risk. They are therefore a sensitive subject and should be treated with respect.

CRUDE MARGIN CONTROL

Many organisations using budgets judge the position (and take remedial action) based on whether the margin is +ve or –ve.



This has two problems

1) it means action is only taken late when the position is already unacceptable

2) it does not help using margins to establish safe values for the system limit.

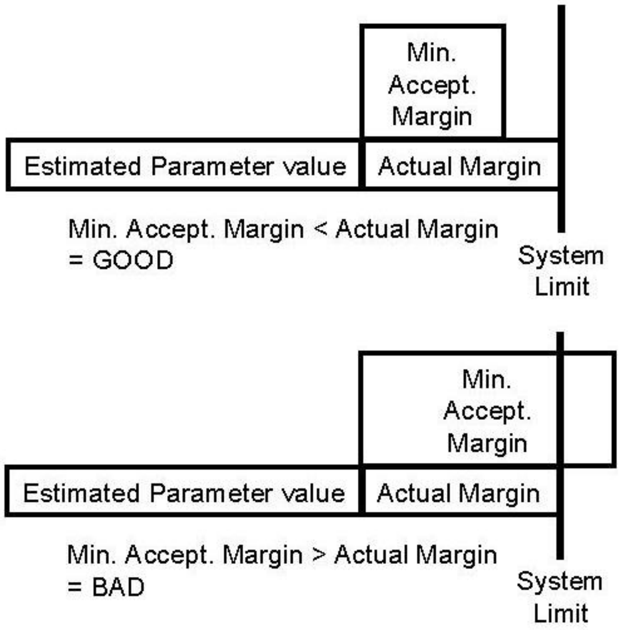
To get around this we need some judgement about what +ve margin is adequate to get a product that works as intended.

MINIMUM ACCEPTABLE MARGIN

To overcome these shortcomings we need to have established some Minimum Acceptable +ve Margin.

The system development team can then act when the margin is less than judged the required minimum.

Also it means a better judgement can be made when the system limits are established.



ARE THE MARGINS ADEQUATE?

Is the margin between estimate of the parameter and the system limit enough to ensure the limit is not reached later when the system is available for operations? This question is important throughout the systems development, but the action taken if the answer is no varies.

In the early stages (before relevant Requirement Specifications are frozen) there is often scope to revise the system limit. After the limit has been frozen then the response to a negative margin is to undertake redesign of the elements involved to make them compliant – and that is always painful.

To establish a Minimum Acceptable Margin we need some assessment of the errors on the original estimate. Sometimes this is done as a single system level assessment but can be more rigorously on an element-by-element bias.

The errors can be evaluated by

1 Analysis
A study of likely variations over the design for which the estimate was made can provide a guide as to a suitable margin. But this only covers “known unknowns” and misses the “unknown unknowns”. This approach has a poor record in practice.

2 Past experience
Where good historical data exists on how accurate such estimates have been in the past (a version of parametric analysis)

.
As an example, a good guideline on mass uncertainty for many components is:

1% for rebuild of an existing product
3% for a slight modification to the product
5% - 8% for major modification to existing product
10% for a new product
15% for a .new product with uncertain interfaces (e.g. electrical harness)

3 By Guess and by God
Sometimes you will just have to guess! But it is better than nothing

COMBINING THE ERRORS

If a minimum acceptable margin is established by combining element level error estimates. There are two ways of combining the element estimated errors together to determine if the overall system margin is adequate.

Simple addition - easy and safe but if the errors can go both ways it can produce a very conservative estimate of the minimum acceptable margin.

Root Sum Squared (RSS) - where errors are genuinely random this will give a better estimate of the minimum acceptable margin

The trick is to know when the errors are genuinely random, i.e. have the same probability of going one way as the other. Basic rule here - don't kid yourself, if in doubt ADD, and very important

Errors in MASS, POWER and FINANCE are definitely not random

AN EXAMPLE OF RSS

This is a fictitious (but typical*) examples of a propellant budget for a geostationary communications satellite propulsion subsystem. Errors are 2 sigma estimates based on normal distribution.

Because errors can genuinely go either way (less or more than the estimate) then RSSing is a valid way to estimate the required margin. And in this case it reduces the estimated required margin by a half.

(assuming a 5 year life, 500kg beginning of life mass, solid apogee motor and monopropellant liquid propulsion)*

Manoeuvre	Velocity	Propellant	Error
Transfer Orbit Control	-	0.5 kg	0.1 kg
Apogee Burn Control	-	4.0 kg	0.3 kg
Despin	-	1.5 kg	0.1 kg
Orbit Correction	15 m/s	5.0 kg	0.4 kg
E/W Station keeping	25 m/s	8.5 kg	0.1 kg
N/S Station keeping	225 m/s	81.0 kg	0.8 kg
Attitude Control	-	3.5 kg	0.4 kg
End of Life disposal	85 m/s	29.0 kg	0 kg
Ullage	-	1.5 kg	0.7 kg
TOTAL PROPELLANT REQUIRED		134.5 kg	

Required margin if summed = 2.90 kg
Required margin if RSS = 1.25 kg

ANOTHER EXAMPLE - RF LINK BUDGETS

In telecommunications the transmission equation (gives power received by a radio receiver) is:

$$C = Pt . Lt . Gt . La . Gr . Lr . c / (4 \pi \ R f)2$$

where:

C = received power
Pt = Power of tranmitter
Lt = loss in the path from the transmitter
Gt = Transmitter (Tx) antenna gain
La = Loss in the transmission path
Gr = Receiver (Rx)antenna gain
Lr = receiver losses in antenna and line to receiver
c = Speed of light
R = distance between transmitter and reciever
f = Radio frequency

At first sight an equation like this does not look a promising candidate for a budget – but they are basically a list of terms that together give a value that is either bigger or smaller than the receiver can detect (the system limit).

It is normal practice to convert the terms into decibels [using dB = 10 Log (P1/P2)] and then the terms can be added in a conventional budget format.

LINK BUDGET

(Relative to 1 mWatt)

Item		Value	dB	
EIRP	Power of transmitter	10 log (2,000,000 mWatts)	63.0	dBm
	Tx antenna gain	10 log (1.6)	2.0	dB
Transmitter losses		10 log (0.95)	- 0.2	dB
Path losses		10 log (0.91)	- 0.4	dB
Free space loss	Constant	20.log (C / 4 π)	147.6	dB
	Frequency	-20.log (500,000,000)	-174.0	dBHz
	Range	-20.log (200,000)	-106.0	dBmeters
RX Antenna gain		10 log (2)	3.0	dB
Receiver losses		10 log (0.97)	-.01	dB
Receive power		3.1 x10^{-7} mWatts	-65.1	dBm
Margin			- 4.9	dB
Receiver sensitivity		10^{-7} mWatts	-70.0	dBm

DON'T FORGET SUBSYSTEM AND SYSTEM LEVEL UNCERTAINTIES

In the above we have been dealing with the assessment of the required minimum margin but only considered the component level uncertainties. Often forgotten is that the margin also needs to cover uncertainties at the higher levels (subsystem and system). Allowance for these need to be incorporated into the estimate for the overall minimum acceptable margin.

A common feature on spacecraft is a unit with an acronym like I.F.I.U. standing officially for something like Inter-Face Intercept Unit; but what it really stands for is the "I Forgot It Unit". All the provisions (mass, power, data, floor space etc.) for this unit have to be found from the margins in the spacecraft's budget.

MASS BUDGETS

All budgets are equal, but some budgets are more equal than others.

(with apologies to Orwell)

That is all budgets affect system viability, and so care must be taken to ensure the resource demanded does not exceed what can be supplied. However in theory at least, any short fall can be corrected by alterations to the systems design.

But historically some budgets prove more difficult to control and more expensive to correct than others and in aerospace the most difficult is mass. Mass and mass properties end up as one of the major system headaches on all aircraft and spacecraft systems and therefore merit special attention.

That is why every engineering drawing in an aerospace firm is signed by the "Stress <u>and Weights</u>" department.

Total system level margins on new systems should be 20% or more. Totally new concepts would be better off with as much as 50%. For example; the Apollo Lunar module mass grew by 50% over its development programme.

This is an aerospace example. Other industries will have other critical budgets and these should have special institutionalised procedures for generation, monitor and control of the budget. If these are not in place then this is key area for potential improvement in achieving project success.

HEMPSELL'S "PATENTED" METHOD OF COPING WITH MASS BUDGETS

Even with the traditional institutionalised procedures within the aerospace industry; mass control remains a major problem. While working as an Assistant Project Manager (effectively top mechanical systems engineer on the project) I was painfully aware of the problem of inadequate mass margins incorporated at the initial stages of the project and developed a methodology to try to resolve this. The method has been used on real projects but not on anything actually that ended up being built.

The method has two purposes:

1 - to get as accurate as possible picture of the margin that is actually required.
2 - to stop managers, customers and other pests trying to "use up" the massive margin.

The method involves adding an error margin at every level that there is a specification - i.e. at every level an uncertainty is introduced. On a typical space system that is:

1 Component level - covering design and build uncertainty (with the sort of % error outline in previous overhead). Held by the equipment manufacturer.

2 Subsystem level - to cover uncertainties in subsystem design and mistakes in specification. Held by subsystem contractor.

3 System level - To cover uncertainties in system design and specification and mistakes in subsystem specifications held by system contractor.

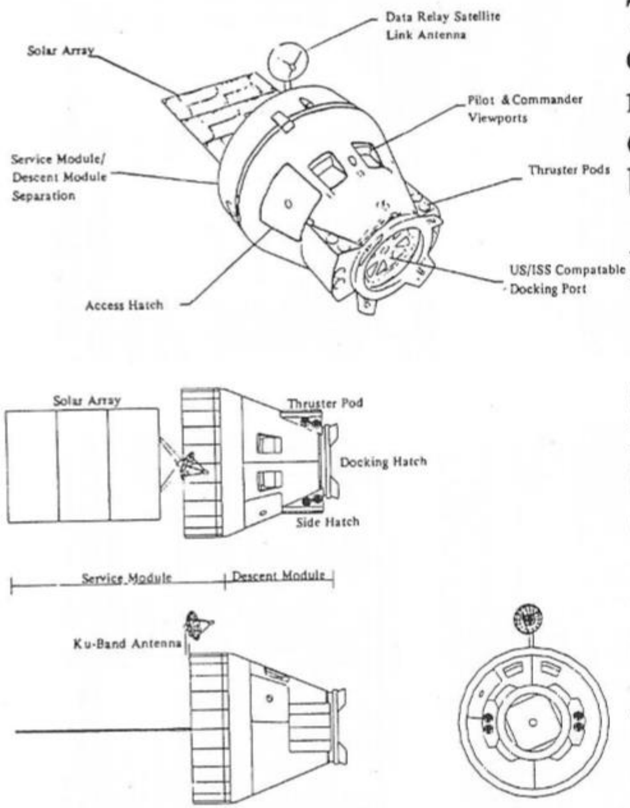
4 Customer - (if appropriate) covering mistakes/changes to system specification. Held by Customer.

Even with modest margins at the various levels (sub 10%) the total margin in the system during the requirement generation phase is typically over 20%. And history suggests that is the sort of margin that is needed, but if you show it simply as a big lump on the end everybody starts wanting to "use" it. Spread the margin throughout the budget and hey presto - nobody argues with it.

It also gives the subsystem engineers confidence that their interests are being looked after and so they are less likely to hide margins.

An example of this methodology in action is shown in the attached example for BAe's Multi-role capsule.

AN EXAMPLE - BAe MULTIROLE CAPSULE



This is an example of subsystem level mass budget. The equipment level budget follows.

Note:

- The way the system is broken into disciplines, then subsystems, then equipment.

- The way the mass margin is built up. With margins held where-ever a requirement specification will be.

SUBSYSTEM	SUBSYSTEM ESTIMATE MASS (kg)	SUBSYSTEM SPECIFIED MASS (kg)	SUBSYSTEM MARGIN %
Mechanical			
Structure	895	1000	11
Thermal Protect	631	730	14
Thermal Control	64	80	20
Mechanisms	313	350	11
Propulsion	164	10	22
POPS	64	70	9
Recovery	236	270	13
Mech.Fittings	21	25	16
Electrical			
Data Management	48	55	13
S-Band Comms	18	20	10
Audio Comms	24	30	20
Ku Comms/Radar	128	145	13
Guilde.Nav.& Con	70	80	12
Power	271	310	13
Habitability			
ECLSS	185	210	12
Galley & Hygiene	71	90	22
Fittings	237	270	12
Loose items	75	85	12
Caution & Warning	36	45	20
TOTAL DRY MASS	3551	4075	
Consumables	930	977	5
Payload	1000	1000	
Margin	1519 (22%)	948 (14%)	
SPEC MASS IN ORBIT	7000	7000	
Escape Tower	756	950	20
LAUNCH MASS	7756	7950	

Reference: Journal of the British Interplanetary Society Vol 42 No 2 February 1989

APPENDIX: MRC MASS BREAKDOWN

This appendix contains the detailed mass breakdown for the Multi-Role Capsule (MRC), down to unit level.

As with all programmes a mass margin between the estimated mass and that specified is required, to allow for uncertainties in design and build. From the outset the MRC study employed a sophisticated mass margin philosophy to ensure;

a) The overall margin is adequate for the design status
b) Any areas of major concern are identified
c) Initial subsystem specification values are available for subsystem level feasibility studies.

The margin philosophy allocates a margin at every level of breakdown for which there is a requirement specification (i.e. System, Subsystem and equipment). This is done even though at this stage in the project the lower level specifications do not exist.

The actual percentages applied were as follows;

i) Equipment level
Mass derived from existing units 2% to 5%
Mass estimated from parametrics etc. 5% to 15%

ii) Subsystem level
A minimum margin of 5% was allocated at subsystem level (in addition to the sum of equipment margins). This being a suitable value for the early stages of a project. Where subsystems have a previous history (on other projects) for large mass excursions from original estimates a larger mass margin was used.

iii) System level
A further margin is required at system level to cover uncertainties at system level. The minimum acceptable margins at this level depends upon the programme status, in the judgement of the study suitable margins would be.

Contract Start – Freeze of system spec – 8%
Preliminary Design Review – Freeze Sub system Spec – 5%
Critical Design Review – Freeze Manuf. Drawings – 2%

Therefore the MRC study, being at an early stage, looked for a System level margin greater than 8%.

A point to make about the system level margin is that it only covers uncertainties in meeting the system specification it does not cover changes in those requirements. In systems where customer requirements strongly influence the engineering design (such as communications satellites) the best approach is have a further customer margin identified. However the MRC which is essentially a transport system with little direct engineering input from the customer this customer controlled margin is assumed included in the quoted payload capability.

Displine: MECHANICAL Subsystem: STRUCTURE

Unit	Est. Mass per Unit (kg)	Number off	Mass per System (kg)	Unit Margin (%)	Unit Spec mass (kg)
Descent Module					
Press Cone	134.0	1	134.0	5	140.7
Bulkhead	38.0	1	38.0	5	39.9
Shear walls	84.0	1	84.0	5	88.2
Attach. Rings	13.0	3	39.0	5	41.0
Rear Cone	45.0	1	45.0	5	47.3
Rear dome	63.0	1	63.0	5	66.2
Shield support	67.0	1	67.0	5	70.4
Pod Structure	12.0	2	24.0	5	25.2
Hatch reinf.	20.0	1	20.0	10	22.0
DM Pyro fit.	35.0	1	35.0	5	36.8
Miscellaneous	154.0	1	154.0	10	169.4
Service Module					
Cylinder	124.0	1	124.0	5	130.2
Beams	20.0	1	20.0	5	21.0
SM Pyro fit.	18.0	1	18.0	5	18.9
Micellaneous	30.0	1	30.0	10	33.0
TOTALS			895.0		950.2
Margins			105.0 +		49.8 *
SUBSYSTEM SPECIFICATION MASS			1000.0		1000.0

\+ Total margin held by subsystem 11%
* Subsystem level margin 5%

Displine: MECHANICAL Subsystem: THERMAL CONTROL

Unit	Est. Mass per Unit (kg)	Number off	Mass per System (kg)	Unit Margin (%)	Unit Spec mass (kg)
Radiator	8.0	1	8.0	10.0	8.8
Bracket	2.0	1 Set	2.0	10.0	2.2
Pump	3.0	2	6.0	10.0	6.6
Pipework	7.0	1 set	7.0	10.0	7.7
Water/Gycol	10.0	1	10.0	10.0	11.0
Cold Plates	5.0	4	20.0	10.0	22.0
GS Heat Ex	2.0	1	2.0	10.0	2.2
ECLSS Heat Ex	2.0	2	4.0	10.0	4.4
Valves	4.0	1 Set	4.0	10.0	4.4
Miscellaeous	1.0	1	1.0	10.0	1.1
TOTALS			64.0		70.4
Margins			16.0 +		9.6 *
SUBSYSTEM SPECIFICATION MASS			80.0		80.0

\+ Total margin held by subsystem 20%
* Subsystem level margin 12%

Displine: MECHANICAL Subsystem: THERMAL PROTECTION

Unit	Est. Mass per Unit (kg)	Number off	Mass per System (kg)	Unit Margin (%)	Unit Spec mass (kg)
Descent Module					
DM Blankets	75.0	1 Set	75.0	10	82.5
Upper protect	90.0	1	90.0	10	99.0
Heat Shield	400.0	1	400.0	10	440.0
Paint	10.0	1	10.0	10	11.0
Service Module					
SM Blankets	36.0	1 Set	36.0	10	39.6
SM Protect	15.0	1	15.0	10	16.5
Paint	5.0	1	5.0	10	5.5
TOTALS			631.0		694.1
Margins			99.0 +		35.9 *
SUBSYSTEM SPECIFICATION MASS			730.0		730.0

\+ Total margin held by subsystem 14%
* Subsystem level margin 5%

Displine: MECHANICAL Subsystem: MECHANISMS

Unit	Est. Mass per Unit (kg)	Number off	Mass per System (kg)	Unit Margin (%)	Unit Spec mass (kg)
Docking Port					
Ring Guide	78.0	1	78.0	5	81.9
Latches	40.0	1 Set	40.0	5	42.0
Structure	30.0	1	30.0	5	31.5
Flange/Seal	62.0	1	62.0	5	65.1
Hatch	40.0	1	40.0	5	42.0
Control Elec.	13.0	1	13.0	10	14.3
Side Hatch					
Hatch	40.0	1	40.0	5	42.0
Thermal Protect	10.0	1	10.0	15	11.5
TOTALS			313.0		330.3
Margins			37.0 +		19.7 *
SUBSYSTEM SPECIFICATION MASS			350.0		350.0

\+ Total margin held by subsystem 10%
* Subsystem level margin 6%

Displine: MECHANICAL Subsystem: PRIMARY INTEGRAL PROPULSION

Unit	Est. Mass per Unit (kg)	Number off	Mass per System (kg)	Unit Margin (%)	Unit Spec mass (kg)
Latch Valve	0.4	30	12.0	2	12.3
HF Latch Valve	2.3	4	9.2	2	9.4
F/D Valve	0.3	4	1.2	2	1.2
Press. Trans.	0.3	6	1.8	2	1.8
Test Port	0.1	11	1.1	2	1.1
Press. Reg.	1.0	2	2.0	5	2.1
Relief Valve	1.0	1	1.0	0	1.0
Non Ret Valve	0.2	4	0.8	2	0.8
Filter	0.5	2	1.0	2	1.0
Thrusters	3.4	12	40.8	2	41.6
Press Tank	16.0	2	32.0	2	32.6
Prop Tank	13.0	4	52.0	8	56.2
Pipework	5.0	1 Set	5.0	15	5.8
Control Elec.	4.0	1	4.0	10	4.4
TOTALS			163.9		171.3
Margins			46.1		38.7
SUBSYSTEM SPECIFICATION MASS			210.0		210.0

+ Total margin held by subsystem 22%
* Subsystem level margin 18%

Displine: MECHANICAL Subsystem: PROXMITY OPERATIONS PROPULSION

Unit	Est. Mass per Unit (kg)	Number off	Mass per System (kg)	Unit Margin (%)	Unit Spec mass (kg)
Tank	16.0	2	32.0	8	34.6
Press. Trans.	0.3	3	0.9	2	0.9
F/D Valve	0.1	4	0.4	2	0.4
Latch Valve	0.4	4	1.6	2	1.6
Relief Valve	0.5	1	0.5	2	0.5
Pressure Reg	1.0	1	1.0	5	1.1
Thruster	1.0	20	20.0	5	21.0
Pipework	3.0	1 set	3.0	15	3.5
Filter	0.3	2	0.6	5	0.6
Control Elec	4.0	1	4.0	10	4.4
TOTALS			64.0		68.6
Margins			6.0 +		1.4 *
SUBSYSTEM SPECIFICATION MASS			70.0		70.0

+ Total margin held by subsystem 9%
* Subsystem level margin 2%

Displine: MECHANICAL Subsystem: RECOVERY

Unit	Est. Mass per Unit (kg)	Number off	Mass per System (kg)	Unit Margin (%)	Unit Spec mass (kg)
Parachutes	45.0	4	180.0	5	189.0
Drouges	12.0	4	48.0	5	50.4
Flotation Collar	8.0	1	8.0	5	8.4
TOTALS			236.0		247.8
Margins			34.0 +		22.2 *
SUBSYSTEM SPECIFICATION MASS			270.0		270.0

+ Total margin held by subsystem 13%
* Subsystem level margin 8%

Displine: MECHANICAL Subsystem: MECHANICAL FITTINGS

Unit	Est. Mass per Unit (kg)	Number off	Mass per System (kg)	Unit Margin (%)	Unit Spec mass (kg)
Grapple point	12.5	1	12.5	2	12.8
Grab Handle	0.5	4	2.0	5	2.1
Equip. Bolts	5.0	1 Set	5.0	10	5.5
Harness tiedown	1.0	1	1.0	10	1.1
TOTALS			20.5		21.5
Margins			4.5 +		3.5 *
SUBSYSTEM SPECIFICATION MASS			25.0		25.0

+ Total margin held by subsystem 18%
* Subsystem level margin 14%

Displine: ELECTRICAL Subsystem: DATA MANAGMENT

Unit	Est. Mass per Unit (kg)	Number off	Mass per System (kg)	Unit Margin (%)	Unit Spec mass (kg)
Flight Recorder	5.0	1	5.0	5	5.3
Command & Tele	10.0	1	10.0	5	10.5
Command Stations	10.0	2	20.0	5	21.0
Com/Diplex	4.0	1	4.0	5	4.2
Signal harness	5.0	1	5.0	10	5.5
Consumable Mon.	4.0	1	4.0	10	4.4
TOTALS			48.0		50.9
Margins			7.0 +		4.1 *
SUBSYSTEM SPECIFICATION MASS			55.0		55.0

+ Total margin held by subsystem 13%
* Subsystem level margin 9%

Displine: ELECTRICAL Subsystem: S-BAND TELECOMMUNICATIONS

Unit	Est. Mass per Unit (kg)	Number off	Mass per System (kg)	Unit Margin (%)	Unit Spec mass (kg)
S-band TX/RX	3.0	2	6.0	5	6.3
Switch	0.5	1	0.5	5	0.5
Antenna	0.5	2	1.0	5	1.1
RF Harness	1.0	1	1.0	10	1.1
TOTALS			7.5		9.0
Margins			2.5 +		1.0 *
SUBSYSTEM SPECIFICATION MASS			10.0		10.0

+ Total margin held by subsystem 25%
* Subsystem level margin 10%

Displine: ELECTRICAL Subsystem: AUDIO COMMUNICATIONS

Unit	Est. Mass per Unit (kg)	Number off	Mass per System (kg)	Unit Margin (%)	Unit Spec mass (kg)
Intercoms	1.0	4	4.0	5	4.2
Audio Mixer	2.0	1	2.0	5	2.1
EMU Tele extract	3.0	2	6.0	5	6.3
UHF TX/RX	10.0	1	10.0	5	10.5
Antenna	0.5	2	1.0	5	1.1
RF Harness	1.0	1	1.0	10	1.1
TOTALS			24.0		25.3
Margins			6.0 +		4.7 *
SUBSYSTEM SPECIFICATION MASS			30.0		30.0

+ Total margin held by subsystem 20%
* Subsystem level margin 16%

Displine: ELECTRICAL Subsystem: POWER

Unit	Est. Mass per Unit (kg)	Number off	Mass per System (kg)	Unit Margin (%)	Unit Spec mass (kg)
Solar Panels	10.0	3	30.0	5	31.5
Array Deploy.	6.0	1	6.0	5	6.3
Array Regulator	6.6	1	6.0	10	6.6
Battery	35.0	4	140.0	5	147.0
Battery Control	3.0	4	12.0	10	13.2
Ground Umbilical	2.0	1	2.0	5	2.1
Control Box	15.0	1	15.0	10	16.5
Pyro Control Box	5.0	2	10.0	5	10.5
Harness (DM)	30.0	1	30.0	15	34.5
Harness (SM)	20.0	1	20.0	15	23.0
TOTALS			271.0		291.2
Margins			39.0 +		18.8 *
SUBSYSTEM SPECIFICATION MASS			310.0		310.0

+ Total margin held by subsystem 13%
* Subsystom level margin 6%

Displine: ELECTRICAL Subsystem: Ku COMMS/RADAR

Unit	Est. Mass per Unit (kg)	Number off	Mass per System (kg)	Unit Margin (%)	Unit Spec mass (kg)
Crew Interface	5.0	1	5.0	5	5.3
Antenna control	12.0	1	12.0	5	12.6
Ku TX/RX	60.0	1	60.0	5	63.0
Video Diplexer	10.0	1	10.0	5	10.5
Antenna	21.0	1	21.0	5	22.1
Radar Elec.	20.0	1	20.0	5	21.0
TOTALS			128.0		134.5
Margins			17.0 +		10.5 *
SUBSYSTEM SPECIFICATION MASS			145.0		145.0

+ Total margin held by subsystem 12%
* Subsystem level margin 7%

Displine: ELECTRICAL Subsystem: GUIDANCE NAVIGATION AND CONTROL

Unit	Est. Mass per Unit (kg)	Number off	Mass per System (kg)	Unit Margin (%)	Unit Spec mass (kg)
Inertial Ref.	10.0	2	20.0	10	22.0
Control Computer	15.0	1	15.0	5	15.8
Manual Control	8.0	1	8.0	8	8.6
Sun Sensor	2.0	2	4.0	5	4.2
Star Mapper	13.0	1	13.0	5	13.7
GPS Reciever	2.0	1	2.0	5	2.1
GPS Antenna	0.5	2	1.0	5	1.1
LAN Bridge	3.0	1	3.0	5	3.2
GNS LAN Harness	4.0	1	4.0	10	4.4
TOTALS			70.0		75.1
Margins			10.0 +		4.9 *
SUBSYSTEM SPECIFICATION MASS			80.0		80.0

+ Total margin held by subsystem 13%
* Subsystem level margin 6%

Displine: HABITABILITY Subsystem: ECLSS

Unit	Est. Mass per Unit (kg)	Number off	Mass per System (kg)	Unit Margin (%)	Unit Spec mass (kg)
Oxygen Tanks	16.0	2	32.0	2	32.6
Air Tanks	16.0	4	64.0	2	65.3
Pipework	1.5	1 set	1.5	15	1.7
F/D Valves	0.4	4	1.6	5	1.7
Pressure Reg	0.5	8	4.0	5	4.2
Atmos. Cont.	51.0	1	51.0	5	53.6
Press. Cont.	20.0	1	20.0	5	21.0
LiOH Store	4.0	1	4.0	5	4.2
ECLSS Cont.	7.0	1	7.0	10	7.7
TOTALS			185.1		192.0
Margins			24.9 +		18.0 *
SUBSYSTEM SPECIFICATION MASS			210.0		210.0

+ Total margin held by subsystem 12%
* Subsystem level margin 9%

Displine: HABITABILITY Subsystem: GALLEY

Unit	Est. Mass per Unit (kg)	Number off	Mass per System (kg)	Unit Margin (%)	Unit Spec mass (kg)
Trash Container	0.45	2	0.9	5	1.0
Water Dispenser	0.5	1	0.5	2	0.5
Food Prep	2.0	1	2.0	5	2.1
Water Store Tank	2.5	4	10.0	10	11.0
Water Heater	5.0	1	5.0	10	5.5
Washing Station	5.0	1	5.0	10	5.5
F/D Valve	0.4	1	0.4	2	0.4
Structure	11.0	1	11.0	10	11.0
TOTALS			34.8		37.0
Margins			10.2 +		8.0 *
SUBSYSTEM SPECIFICATION MASS			45.0		45.0

+ Total margin held by subsystem 22%
* Subsystem level margin 18%

Displine: HABITABILITY Subsystem: HYGIENE

Unit	Est. Mass per Unit (kg)	Number off	Mass per System (kg)	Unit Margin (%)	Unit Spec mass (kg)
Seat	3.0	1	3.0	5	3.2
Gate Valve	1.0	1	1.0	5	1.1
Motor	4.0	1	4.0	10	4.4
Slinger Tines	2.0	1	2.0	5	2.1
Fixed Tines	2.0	1	2.0	5	2.1
Handles	0.5	1	0.5	2	0.5
Filters	0.5	3	1.5	5	1.6
Framework	10.0	1	10.0	10	11.0
Fan Separators	3.0	1	3.0	5	3.2
Urinal	2.0	1	2.0	5	2.1
Restraint	0.6	3	1.8	5	1.9
Vac. Cont. Valve	0.5	1	0.5	5	0.5
Waste Water Tank	5.0	1	5.0	5	5.3
TOTALS			36.3		39.0
Margins			8.7 +		6.0 *
SUBSYSTEM SPECIFICATION MASS			45.0		45.0

+ Total margin held by subsystem 19%
* Subsystem level margin 13%

Displine: HABITABILITY Subsystem: FITTINGS

Unit	Est. Mass per Unit (kg)	Number off	Mass per System (kg)	Unit Margin (%)	Unit Spec mass (kg)
Privacy Screen	5.0	1	5.0	5	5.3
Couch	25.0	4	100.0	2	102.0
Grab Handles	0.5	8	4.0	5	4.2
Floor Covers	6.0	1	6.0	5	6.3
Payload Bay	50.0	1	50.0	5	52.5
Main Lighting	3.0	1 Set	3.0	10	3.3
Personal Stowage	7.0	4	28.0	10	30.8
Suit Stowage	8.0	2	16.0	5	16.8
Nav. Lights	0.5	2	1.0	10	1.1
Power Point	0.3	1	0.3	5	0.3
Miscel. Stowage	24.0	1	24.0	5	25.2
TOTALS			237.3		247.8
Margins			32.7 +		22.2 *
SUBSYSTEM SPECIFICATION MASS			270.0		270.0

+ Total margin held by subsystem 12%
* Subsystem level margin 8%

Displine: HABITABILITY Subsystem: LOOSE ITEMS

Unit	Est. Mass per Unit (kg)	Number off	Mass per System (kg)	Unit Margin (%)	Unit Spec mass (kg)
Port. Oxygen	1.8	4	7.2	2	7.3
Survival Kit	19.1	1	19.1	2	19.5
Life vests	1.2	4	4.8	2	4.9
First Aid Kit	8.0	1	8.0	2	8.2
Tool Kit	10.0	1	10.0	5	10.5
Video Recorder	7.5	1	7.5	5	7.9
Video Camera	12.0	1	12.0	2	12.2
Sound Tape	1.0	2	2.0	5	2.1
Flight Manuals	4.0	1 set	4.0	5	4.2
TOTALS			74.6		76.8
Margins			13.4 +		11.2
SUBSYSTEM SPECIFICATION MASS			88.0		88.0

+ Total margin held by subsystem 15%
* Subsystem level margin 13%

Displine: HABITABILITY Subsystem: CAUTION AND WARNING

Unit	Est. Mass per Unit (kg)	Number off	Mass per System (kg)	Unit Margin (%)	Unit Spec mass (kg)
C&W Control	16.0	1	16.0	5	16.8
Fire Ex (fitted)	10.0	1 set	10.0	10	11.0
Fire Ex (losse)	5.0	2	10.0	10	11.0
TOTALS			36.0		38.8
Margins			14.0 +		11.2 *
SUBSYSTEM SPECIFICATION MASS			50.0		50.0

+ Total margin held by subsystem 28%
* Subsystem level margin 22%