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PROJETO E CONSTRUÇÃO DE UMA ESTAÇÃO MULTI-USO PARA TESTES VÁCUO-TÉRMICOS

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INTRODUÇÃO

Quando um material é submetido a vácuo o fenômeno da desgaseificação é intensificado. Tal fenômeno pode ser definido como sendo a liberação de moléculas das superfícies do material e torna-se mais crítico a medida em que se aumenta a temperatura. Pode ocorrer também que uma substância no estado líquido ou sólido atinja a pressão de vapor na respectiva temperatura e se evapore.

Para aplicações espaciais é importante que a taxa de desgaseificação seja baixa pois as moléculas liberadas podem se depositar sobre superfícies de satélites artificiais, veículos ou experimentos espaciais provocando fenômenos tais como efeito corona, distorções de imagens de camêras, alterações de propriedades termo-ópticas de superfícies, mudanças no comportamento de células solares entre outros fatores, comprometendo assim o seu funcionamento e a confiabilidade dos dados coletados.

Associado ao vácuo existe também o problema da falta de convecção de ar gerar mudança nos modos de transferência de calor. Isso pode ocasionar gradientes de temperatura relativamente altos ou até mesmo superaquecimento de equipamentos. Variações térmicas podem levar a variações dimensionais provocadas por expansão e contração e estas por sua vez gerar trincas ou rupturas.

O desenvolvimento da Estação Multi-Uso para Testes Vácuo-Térmicos será de grande importância no suporte à realização de testes em materiais que apresentem taxas de desgaseificação e/ou evaporação desconhecidas ou altas e também de materiais cujo comportamento térmico sob vácuo não é perfeitamente definido. Tais testes possibilitarão levantar e analisar parâmetros para qualificação prévia de materiais que poderão integrar sistemas espaciais ou para estudos de melhorias nas técnicas de simulação espacial.

DESCRIÇÃO DA ESTAÇÃO

A Estação Multi-Uso será composta basicamente por um sistema de vácuo, um sistema de controle térmico, um colar de flanges e um sistema de monitoração e controle de dados.

Integrarão o sistema de vácuo, uma campânula de aço inoxidável, uma bomba mecânica e uma bomba turbomolecular. A pressão mínima no interior da campânula será da ordem de 10^{-6} Torr e poderá ser atingida operando-se em série as bombas mecânica e turbomolecular e desejando-se trabalhar com baixo vácuo (pressão até 10^{-2} Torr) opera-se somente a bomba mecânica. A pressão poderá ser controlada em qualquer valor de ambiente a 10^{-6} Torr através de injeção de nitrogênio gasoso por uma válvula µmétrica. Ao fim do teste o sistema deverá ser repressurizado ou mantido em vácuo através de uma válvula gaveta.

O colar de flanges ligará a campânula ao sistema de bombas de vácuo e nele serão instaladas as flanges do cabeçote sensor do espectrometro de massas, da bomba mecânica, do sistema de refrigeração e aquecimento, do sensor de vácuo, da válvula µmétrica, da válvula de repressurização e dos feedthroughs para RF, sinais elétricos e termopares.

O sistema térmico e o sistema de monitoração e controle ainda estão em fase de estudo. Basicamente, o sistema térmico será composto por uma camisa térmica, confeccionada em material que apresente alta emissividade e absortividade e seja bom condutor de calor, e acoplada à camisa existirão serpentinas através das quais se fará circular um fluido aquecido ou resfriado. A troca térmica entre o equipamento testado e a camisa térmica ocorrerá por radiação e convecção em testes com pressão de até 10^{-4} Torr, e em testes com alto vácuo a troca térmica por convecção é mínima, podendo portanto ser desprezada. O sistema de monitoração e controle deverá conter medidores de pressão e controladores e medidores de temperatura do equipamento e do fluido.

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MINISTÉRIO DA CIÊNCIA E TECNOLOGIA
INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS

RELATÓRIO FINAL DE BOLSA DE INICIAÇÃO CIENTÍFICA PIBIC / INPE

TÍTULO: PROJETO E CONSTRUÇÃO DE UMA ESTAÇÃO MULTI-USO PARA TESTES VÁCUO-TÉRMICOS

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1 - INTRODUÇÃO TEÓRICA

1.1 - O fenômeno da degaseificação

Um gás ou um vapor qualquer, contido em um volume em vácuo, de um modo geral, está em duas fases distintas: uma fase "solta" denominada fase gasosa, e outra "presa" às superfícies internas da câmara denominada fase adsorvida.

Se conectarmos a câmara a uma bomba de vácuo, poderemos observar que a fase gasosa é bombeada com relativa rapidez enquanto a fase adsorvida leva um certo tempo para dessorver das superfícies internas. Esse tempo varia conforme o gás e a natureza das superfícies. Gases inertes ou pouco reativos dessorvem com muita rapidez de qualquer superfície. Gases que apresentam momento de dipolo molecular elevado levam mais tempo para dessorver, mesmo de superfícies quimicamente inertes como o vidro. Já o tempo de dessorção pode ser extremamente elevado quando há afinidade química entre o gás e a substância da qual a superfície é constituida.

O fenômeno de adsorção ocorre devido a existência de forças de interação entre a superfície e as moléculas do gás. Esse efeito é convenientemente descrito em termos da energia potencial de interação U. A figura 1 representa U em função da distância r da molécula adsorvida à superfície. A energia correspondente ao mínimo da curva é E_a. A molécula adsorvida oscila em torno da posição de equilíbrio r_o. Portanto r_o é a distância média molécula-superfície e E_a é a energia potencial média, que chamaremos de energia de adsorção.

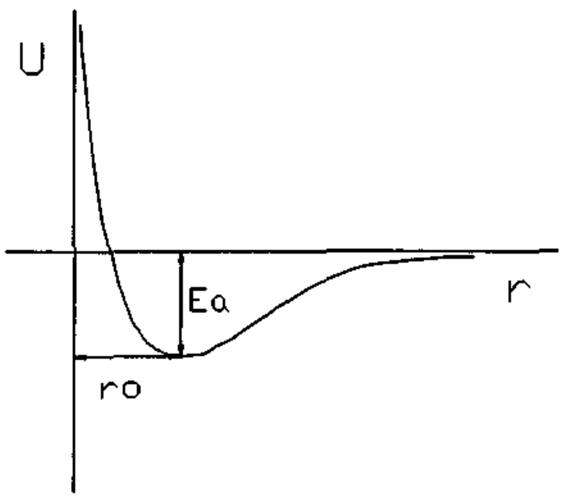


Figura 1

Dependendo do caso, a adsorção de uma molécula pode ser caracterizada por duas etapas consecutivas. Numa primeira etapa a molécula adere fracamente à superfície para em seguida passar a ser mais fortemente ligada, mediante o fornecimento ao sistema molécula-superfície, de uma energia de ativação (em geral calor). Nesse caso a adsorção é classificada como ativada e a dependência do respectivo potencial com a coordenada r é mostrada na figura 2.

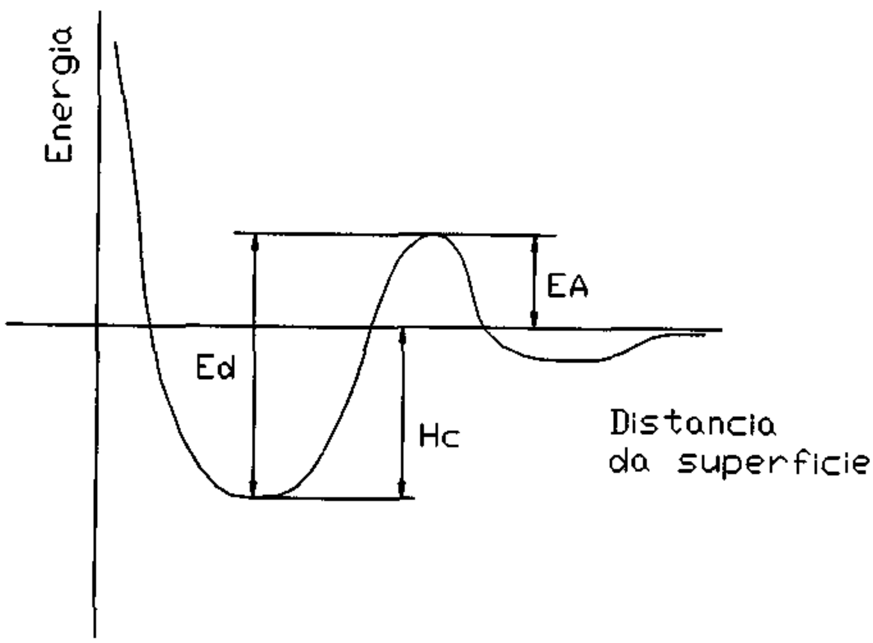


Figura 2

Pela simples observação da figura 1 vemos que a energia cinética mínima necessária para que a partícula escape do potencial de interação - chamada de energia de dessorção E_d é $E_d=E_a$. Da mesma forma, a análise da figura 2 mostra que $E_d=H_c+E_A$ onde H_c é chamado de calor de adsorção e E_A de energia de ativação. A energia E_d pode ser transferida à molécula por meios térmicos (aquecendo-se a superfície) ou mecanicamente (por exemplo: bombardeamento da camada adsorvida por ions pesados).

Dependendo do valor de E_d classificamos a adsorção em duas categorias distintas:

$E_d < 20$ Kcal/mol: adsorção física

$E_d > 20$ Kcal/mol: quimissorção

Na adsorção física, forças do tipo de Van der Waals (interação entre dipolos moleculares) estão envolvidas. Essas forças são fracas, resultando em energias de adsorção e de dessorção relativamente pequenas. Já na quimissorção as forças de interação são mais fortes, havendo ligações químicas propriamente ditas, que resultam da troca de elétrons entre as moléculas adsorvidas e a superfície.

Após a adsorção, uma molécula permanece na superfície um certo tempo médio que depende da energia de dessorção e da temperatura da superfície. Esse tempo médio de permanencia t_s é dado pela equação de Frenkel:

$$t_s = t_o\, e^{Ed/RT} \qquad (1)$$

onde R é a constante universal dos gases e t_o é o período de oscilação da molécula na superfície (aproximadamente 10^{-13} segundos) . Como a equação anterior depende exponencialmente de E_d teremos uma vasta gama de valores de t_s.

1.1.2 - Taxa de adsorção

A razão segundo a qual um gás adsorve numa dada superfície é dada por:

$$dN/dt = sv \qquad (2)$$

A taxa de adsorção dN/dt é dada em moléculas /cm^2.s , v é a densidade de impactos moleculares e s é um fator denominado de probabilidade de adesão. O fator s é definido como a razão entre o número de moléculas que adsorvem por cm^2 por segundo na superfície, e o número de moléculas que incidem por cm^2 por segundo. Portanto $o \leq s \leq 1$.

Substituindo a expressão para v na equação 2 teremos:

$$dN/dt = 3{,}5 \,.\, 10^{22}\, sP \,/\, (MT)^{1/2} \qquad (3)$$

onde P é a pressão em Torr, M é a massa molecular do gás em gramas e T a temperatura em K.

Consideremos uma superfície inicialmente limpa, (isto é, uma superfície inicialmente livre de moléculas adsorvidas). Se P for constante, a taxa dN/dt tem o seu valor máximo quando se inicia o processo de adsorção e diminui continuamente tendendo para um valor constante. Esse efeito é devido ao fato de que s não é constante mas diminui a medida que o número de moléculas adsorvidas por cm^2 aumenta.

1.1.3 - Taxa de dessorção

A taxa de dessorção dN/dt de moléculas de uma dada superfície é diretamente proporcional ao número de moléculas adsorvidas por unidade de área N e inversamente proporcional ao tempo de permanência t_s:

$$dN/dt = N/t_s = (N/t_o)\, e^{-Ed/RT} \qquad (4)$$

Multiplicando ambos os lados da equação 4 por KT, onde K é a constante de Boltzmann (1,03 . 10^{-22} Torr l /K) e T a temperatura absoluta, teremos a taxa de degaseificação devida a dessorção:

$$qd = 1{,}03 \,.\, 10^{-22}\, TN/t_o\, e^{-Ed/RT} \qquad (5)$$

1.1.4 -Equilíbrio entre as fases gasosa e adsorvida - Isotermas de Adsorção

Consideremos uma dada superfície em presença de um determinado gás. Esse gás irá formar uma camada adsorvida. Para qualquer temperatura T>0K haverá dessorção de moléculas da superfície, na taxa dada pela equação 4 . Por outro lado, a superfície é continuamente bombardeada pelas moléculas do gás e a taxa de adsorção, conforme já discutido, é dada pela equação 3. Na situação de equilíbrio essas duas taxas são iguais :

$$(dN/dt)_{des} = (dN/dt)_{ads} \qquad (6)$$

Isso implica em um valor de equilíbrio de N que é uma constante para uma dada pressão e uma dada temperatura. De fato, a substituição das equações 3 e 4 em 6 resulta em:

$$N_{eq} = [(3{,}5 \,.\, 10^{22}\, t_o s\, e^{Ed/RT}) / (MT)^{1/2}]\, P \qquad (7)$$

onde N_{eq} é o valor admitido por N quando o sistema está em equilíbrio. Conforme mostra a equação 7, quanto maior T menor será a quantidade de gás na fase adsorvida.

1.1.5 - Evaporação

Consideremos uma substância em equilíbrio termodinâmico com o seu próprio vapor. Nessa condição, a essa pressão de equilíbrio, chamaremos de pressão de vapor da substância considerada. Partindo da equação de Clausius-Clapeyron podemos chegar à dependência entre a pressão de vapor P_v de substâncias sólidas ou líquidas e a temperatura absoluta T:

$$P_v = Ce^{-H/RT}$$

onde H é o calor latente de vaporização, R a constante universal dos gases e C uma constante.

Sabendo-se qual é o valor de P_v para um determinado sólido à uma dada temperatura podemos determinar qual a sua taxa de evaporação. Quando a substância está em equilíbrio com o seu próprio vapor

$$(dN/dt)_{evap} = (dN/dt)_{ads}$$

onde $(dN/dt)_{evap}$ é o número de moléculas evaporadas por cm^2 por segundo e $(dN/dt)_{ads}$ é o número readsorvido por cm^2 por segundo. Essa última expressão é simplesmente a taxa de adsorção dada pela equação 3 . Portanto:

$$(dN/dt)_{evap} = 3{,}5 \ . \ 10^{22} \ s \ P_v \ / \ (MT)^{1/2} \qquad (8)$$

A única distinção entre as equações 3 e 8 é que a pressão em 8 é P_v.

Para obter a taxa de degaseificação q_e devida a evaporação basta multiplicar ambos os lados da equação 8 por KT:

$$q_e = 3{,}6 \ (T/M)^{1/2} \ s \ P_v \qquad (9)$$

1.1.6 - Degaseificação de substâncias

Como vimos, uma substância pode degaseificar tanto devido a dessorção da camada adsorvida como por evaporação da própria substância. A esses dois efeitos pode se juntar um terceiro que é o de emissão de gases que estão em solução dentro da substância e que evolam da mesma por um processo de difusão. O processo de degaseificação por difusão, como os demais, varia exponencialmente com a temperatura.

Os metais, de um modo geral, contém uma quantidade de gás que varia entre 10 e 100% do seu volume (em condições normais de temperatura e pressão). Os gases mais comumente encontrados são CO, CO_2, O_2, H_2 e N_2. A taxa de degaseificação por difusão em alguns casos é significativa em comparação com as outras.

No caso mais geral, a taxa de degaseificação total q_t de uma dada substância é dada por :

$$q_t = q_d + q_e + q_p$$

onde q_d, q_e e q_p são as taxas correspondentes a dessorção, evaporação e difusão.

2 - OBJETIVOS DO PROJETO

O Laboratório Vácuo-Térmico do LIT / INPE realiza testes vácuo-térmicos, de equipamentos qualificados para vácuo, em Câmaras de Simulação Espacial. Testes de equipamentos em geral, cujos materiais componentes não apresentam baixa taxa de degaseificação ou apresentam taxa de degaseificação desconhecida, não são realizados em Câmaras de Simulação Espacial pois podem comprometer os níveis aceitáveis de contaminação das Câmaras.

O laboratório possui também uma Estação de Ensaios de Materiais Voláteis Condensáveis, utilizada para analisar e qualificar materiais canditados a utilização em sistemas espaciais.

O desenvolvimento da Estação Multi-Uso para Testes Vácuo-Térmicos será de grande importância no suporte à realização dos testes de equipamentos em geral, tais como subsistemas aviônicos ou embarcados em balões estratosféricos ou mesmo os modelos de engenharia de subsistemas de satélites.

A Estação Multi-Uso possibilitará também desenvolvimentos na área de pesquisa, tais como a determinação e análise de parâmetros no estudo de materiais que posteriormente poderão integrar sistemas espaciais. Isso se torna importante na seleção prévia de materiais a serem submetidos a testes na Estação de Ensaios de Materiais Voláteis Condensáveis, pois através dos resultados preliminares será possível eliminar materiais de baixa qualidade para uso espacial e que pudessem eventualmente contaminar a Estação de Ensaios.

Será possível também realizar pesquisas para desenvolvimento de novas técnicas na área de simulação espacial, ou mesmo para aperfeiçoamento das técnicas já existentes.

O crescente aumento das solicitações dos testes acima mencionados justifica a construção da Estação Multi-Uso para Testes Vácuo-Térmicos.

3 - DESCRIÇÃO DA ESTAÇÃO MULTI-USO PARA TESTES VÁCUO-TÉRMICOS:

3.1 - Elementos principais:

A Estação Multi-Uso para Testes Vácuo-Térmicos será composta basicamente por:

- um sistema de bombas de vácuo com capacidade de 1500l/s;

- uma campânula de aço inoxidável;

- uma válvula gaveta para alto vácuo;

- conjunto de camisas térmicas;

- um colarinho de flanges com entrada para:
    . bomba mecânica
    . sensor de vácuo
    . sistema de refrigeração
    . válvula µmétrica
    . válvula de repressurização
    . cabeçote sensor do espectrômetro de massas
    . *feedthroughs* para termopar, sinais elétricos e RF;

- sistema de monitoração e controle de dados, que por sua vez será composto por:
    . medidor de vácuo
    . medidor e controlador de temperatura
    . sistema de espectrômetro de massas.

3.2 - Características principais:

Campânula:
. Volume: 120l
. Diâmetro: 500mm
. Altura: 600mm
. Espessura: 5mm

Sistema de vácuo:

. Range de operação: Pressão atmosférica a 10^{-6} Torr

. Tempo de bombeamento: baixo vácuo (10^{-2} Torr) = 5 min
alto vácuo (10^{-6} Torr) = 30 min

Sistema térmico: (em fase de estudos)

. Range de operação: -160°C a +150°C
circulação de nitrogênio gasoso

. Transiente de temperatura: ~ 2,0°C/min

3.3 - Princípio de funcionamento:

3.2.1 - Sistema de vácuo:

A câmara de vácuo a ser utilizada será uma campânula cilíndrica com uma das extremidades aberta. Acoplada à campânula existirá um dispositivo motorizado de levantamento que possibilitará o movimento vertical da mesma para a montagem do equipamento a ser testado e 3 janelas de observação para possibilitar o acompanhamento do teste e a visualização de alguma eventual anomalia. A vedação da campânula (entre a extremidade aberta e a base) será efetuada por anéis *o'rings* de Viton.

A pressão no interior da campânula poderá variar entre valores intermediários à pressão atmosférica e 10^{-6} Torr sendo que, desejando-se baixo vácuo (pressão da ordem de 10^{-2} Torr) opera-se somente a bomba mecânica, desejando-se alto vácuo (pressão da ordem de 10^{-6} Torr) será necessário operar as bombas mecânica e turbomolecular em série e para se obter níveis de pressão intermediários haverá uma válvula µmétrica com saída para o ambiente externo e que deverá ser devidamente regulada juntamente com a operação das bombas.

Ao fim da operação das bombas o sistema poderá ser mantido em vácuo através de uma válvula gaveta e encerrado o teste o sistema poderá ser repressurizado através de injeção de nitrogênio gasoso.

3.2.2 - Colar de flanges:

O colar de flanges terá as funções de ligar a campânula ao sistema de bombas de vácuo e comportar todas as flanges do sistema de monitoração e controle de dados, sistema de refrigeração, sistema de vácuo e *feedthroughs*. Entre o colar de flanges e a bomba turbomolecular serão instaladas uma válvula gaveta para alto vácuo e um redutor de diâmetros.

Para a confecção do colar será utilizado um tubo de aço inoxidável de dimensões aproximadas de 400mm de diâmetro, 210mm de altura e 5mm de espessura.

O colar deverá apresentar bom acabamento superficial, principalmente nas superfícies internas, e boa eficiência de vedação, que será feita por anéis *o'rings* de Viton em ambas as extremidades do colar.

3.2.3 - Sistema de controle térmico:

O sistema de controle térmico ainda está em fase de desenvolvimento, e a melhor configuração encontrada até então foi a utilização de uma camisa térmica de geometria e de dimensões bem próximas da campânula e que seria instalada internamente a mesma.

Essa camisa deverá ser confeccionada em material que apresente boas propriedades radiativas, ou seja, alta emissividade e alta absortividade e acoplada a ela deverão existir serpentinas, por onde se fará circular nitrogênio gasoso frio ou previamente aquecido.

A troca térmica entre o equipamento em teste e a camisa térmica deverá ocorrer em quase sua totalidade por radiação, principalmente quando se estiver trabalhando com alto vácuo onde a troca por convecção é desprezível.

3.2.4 - Sistema de monitoração e controle de dados:

O sistema de monitoração e controle de dados também não está definido, mas basicamente terá a função de monitoração dos dados de pressão e monitoração e controle dos dados de temperatura na camisa térmica e no espécime.

Para a monitoração da pressão no interior da campânula pensa-se em utilizar um sensor Pirani para leituras de baixo vácuo e sensor Penning para leituras de alto vácuo ou apenas um sensor compacto que meça toda a escala de pressão. É preciso analisar melhor as vantagens de cada sensor e o seu custo.

Para a monitoração dos dados de temperatura serão utilizados sensores termopar tipo T. Eles deverão ser instalados sobre as superfícies que se desejar monitorar, tanto do equipamento em teste quanto da camisa térmica. A temperatura na camisa térmica será função da maior ou menor injeção de nitrogênio na mesma e esse controle será feito através de um controlador dedicado em função da temperatura especificada para cada teste.

4 - METODOLOGIA

4.1 - Levantamento de dados tecnológicos:

Para definição do sistema de vácuo são necessários especificar a pressão mínima de operação, o tempo de evacuação e o volume a ser bombeado da câmara de vácuo e escolher a bomba ou as bombas que atendam tais parâmetros. As opções de bombas de vácuo são de palhetas rotativas e roots para baixo vácuo e turbomolecular, difusora e criogênica para alto vácuo.

Não se recomenda a utilização de pastas ou graxas para selagem de flanges e válvulas. Em seus lugares devem ser usados *o'rings* de metal ou Viton devido a facilidade de montagem e desmontagem, limpeza, além de melhorar a eficiência de vedação. *O'rings* de Viton são utilizados quando deseja-se vácuo da ordem de 10^{-6} Torr e em temperaturas de até 180°C e os *o'rings* de metal para níveis de vácuo melhor que 10^{-6} Torr e para temperaturas superiores a 180°C.

As opções de material para confecção da campânula são o pirex e o metal. As vantagens do pirex são a facilidade de limpeza em casos de eventuais contaminações, a possibilidade de visualização completa da montagem do teste e uma taxa de degaseificação mais baixa. Utilizando-se metal encontra-se facilidades no projeto da parte estrutural tais como nos dispositivos de levantamento e de fixação do equipamento em teste no interior da campânula. Outra facilidade está na selagem do sistema onde é suficiente a utilização de um *o'ring* simples enquanto para campânula de pirex é necessário *o'rings* de perfis especiais.

As trocas térmicas entre o equipamento em teste e as camisas térmicas podem ocorrer por radiação ou contato. Para obter-se trocas térmicas eficientes, as camisas térmicas devem ser de material que apresente alta emissividade e alta absortividade em caso de troca térmica por radiação e para troca térmica por contato o material deve ser bom condutor de calor. O material precisa também apresentar baixa taxa de degaseificação, uma vez que as camisas serão submetidas a vácuo.

Para o resfriamento das camisas térmicas pode ser utilizado circulação de fluido em serpentinas soldadas nas camisas. O fluido pode ser nitrogênio líquido, água refrigerada ou de unidades geladas. Para o aquecimento podem ser usados *Skin-Heaters,* que são resistências elétricas coladas nas superfícies das camisas, ou mesmo circulação de nitrogênio aquecido por resistências. A escolha do fluido adequado será função da faixa de variação de temperatura desejada.

4.2 - Etapas de trabalho:

Em uma primeira etapa de trabalho foram analisadas as necessidades básicas da Estação Multi-Uso e nesse sentido foram definidos volume e dimensões da câmara de vácuo, capacidade das bombas de vácuo e especificadas todas as flanges do sistema de vácuo, espectrômetro de massas e *feedthroughs*.

Trabalhou-se também no projeto mecânico da câmara a fim de analisar a compatibilização dimensional e a melhor disposição dos subsistemas da Estação.

Iniciou-se também o estudo do sistema de controle térmico, onde se incluem a faixa de variação da temperatura, o fluído a ser utilizado e os perfis das camisas térmicas.

Os passos seguintes englobam a definição do projeto mecânico final da Estação e a fabricação, montagem e integração de todos os subsistemas pertinentes. Montada a Estação deverão ser realizados testes de desempenho funcional e comparado com as especificações previstas no projeto inicial.

4.3 - Dimensionamento do sistema de vácuo:

Pressão final = $5 \cdot 10^{-6}$ Torr
Volume a ser bombeado = 120 l
Tempo de bombeamento = 30 min

O sistema será composto por dois tipos de bombas, visto que apenas uma não é capaz de cobrir o range especificado, ou seja, da pressão atmosférica até $5 \cdot 10^{-6}$ Torr.

O bombeamento será dividido em 3 fases principais:

1ª fase: Evacuação da bomba turbomolecular até a pressão de "crossover". O tempo gasto nesta fase é desprezível em relação ao tempo total.

2ª fase: Evacuação da campânula pela bomba mecânica até a pressão de 10^{-2} Torr. Para o sistema considerado pode se estimar um tempo de evacuação de aproximadamente 5 min, então:

$$\Delta t = K \cdot 2{,}3 \cdot (v/s) \cdot \log (P1/P2)$$

onde v = volume
s = vazão da bomba
P1 = pressão inicial
P2 = pressão final
$\Delta t = t_{final} - t_{inicial}$

K é o fator de correção da vazão em relação ao decaimento da pressão:

Range de pressão (Torr)	K
1000 a 100	1
100 a 10	1,25
10 a 1	1,5
1 a 0,1	2
0,1 a 0,01	4

$\Delta t1 = 1 \,.\, 2{,}3 \,.\, (120/SM) \,.\, \log(760/100)$
$\Delta t1 \,.\, SM = 243$

$\Delta t2 = 1{,}25 \,.\, 2{,}3 \,.\, (120/SM) \,.\, \log(100/10)$
$\Delta t2 \,.\, SM = 345$

$\Delta t3 = 1{,}5 \,.\, 2{,}3 \,.\, (120/SM) \,.\, \log(10/1)$
$\Delta t3 \,.\, SM = 414$

$\Delta t4 = 2 \,.\, 2{,}3 \,.\, (120/SM) \,.\, \log(1/0{,}1)$
$\Delta t4 \,.\, SM = 552$

$\Delta t5 = 4 \,.\, 2{,}3 \,.\, (120/SM) \,.\, \log(0{,}1/0{,}01)$
$\Delta t5 \,.\, SM = 1104$

$(243 + 345 + 414 + 552 + 1104) / SM = 5$
SM = 531,6 l/min (velocidade média de bombeamento no range de pressão atmosférica até 10^{-2} Torr).

Considerando-se diversos fatores como fugas e eficiência da bomba pode se optar por uma bomba com velocidade de bombeamento de 700l/min.

3ª fase: Evacuação da campânula pela bomba turbomolecular até a pressão final de 10^{-6} Torr. O cálculo de bombeamento neste range de pressão é pouco preciso, considerando-se a dificuldade de controlar as condições superficiais internas da campânula, degasagem, material de construção, entre outros fatores.

No entanto, os gases a serem retirados da campânula a esta faixa de vácuo, são quase que totalmente provenientes da degasagem da sua superfície interna, considerando-se uma vedação eficaz nas aberturas de trabalho da campânula.

O cálculo pode ser feito da maneira descrita a seguir para t aproximadamente igual a 30 min:

$\log Q = -2{,}84 - 0{,}264\ t$
$\log Q = -2{,}84 - (0{,}264\ .\ 0{,}5)$
$Q = 1{,}07\ .\ 10^{-3}\ cm^3/h$
$Q/A = 1{,}07\ .\ 10^{-3}\ cm^3/h\ cm^2$

Sendo a área:
$A = \pi \varnothing l + 2(\pi \varnothing^2)/4$
$A = \pi\ .\ 50\ .\ 60 + 2(\ \pi\ .\ 50^2\ )\ /\ 4$
$A = 13351{,}77\ cm^2$

$Q = 1{,}07\ .\ 10^{-3}\ \ .\ \ 13351{,}77$
$Q = 14{,}29\ cm^3/h$

Como produto vazão de massa, temos:

$P.Q = cte = 760\ .\ 14{,}29$
$P.Q = 10860{,}4\ Torr\ cm^3\ /\ h$

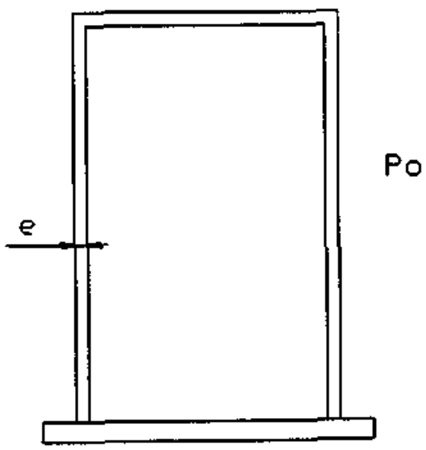
Portanto, à pressão final de 10^{-6} Torr, teremos:

$S = 10860{,}4\ /\ 5\ .\ 10^{-6}$
$S = 2{,}17\ .\ 10^{9} cm^3/h$
S = 603,36 l/s (vazão requerida pela bomba turbomolecular)
Portanto, S = 800 l/s

Utilizaremos um conjunto de bombas disponível no LIT, com capacidade de 1500l/s.

4.4 - Dimensionamento das estruturas mecânicas principais:

4.4.1 - Dimensionamento da espessura da campânula:



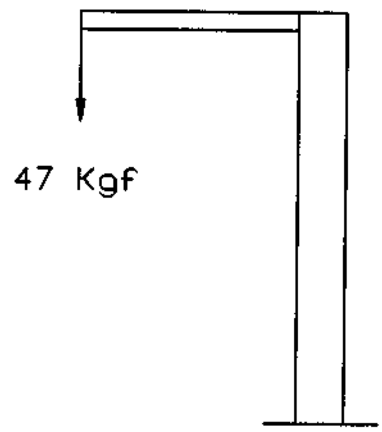
Cilindros sujeitos somente a pressão externa:

$P_{interna} = 0$
$P_{externa}$ (p0) = $1 Kgf/cm^2$
material da campânula: aço inoxidável

$\sigma t = p0 (R^2 + r^2) / (R^2 - r^2)$
$\sigma t = 1 (25{,}5^2 + 25^2) / (25{,}5^2 - 25^2)$
$\sigma t = 50{,}50 \text{ Kgf/cm}^2$

$\sigma adm = \sigma esc / FS = 275 / 4$
$\sigma adm = 68{,}75 \text{ MN/m}^2 \Rightarrow \sigma adm = 701{,}53 \text{ Kgf/cm}^2$

4.4.2 - Dimensionamento do dispositivo de levantamento:



Determinação do peso da campânula:

Material: Aço inoxidável
Peso específico: 7920 Kg/m^3

Volume do cilindro: $\pi \cdot h \cdot (R^2 - r^2)$
$V1 = \pi \cdot 0{,}6 \cdot (0{,}255^2 - 0{,}25^2) = 4{,}759 \cdot 10^{-3} \text{ m}^3$
Peso do cilindro: $\gamma \cdot V$
$P1 = 7920 \cdot 4{,}759 \cdot 10^{-3} = 37{,}69 \text{ Kg}$

Volume da tampa: $\pi \cdot R^2 \cdot e$
$V2 = \pi \cdot 0{,}255^2 \cdot 0{,}005 = 1{,}021 \cdot 10^{-3}\ m^3$
Peso da tampa: $\gamma \cdot V$
$P2 = 7920 \cdot 1{,}021 \cdot 10^{-3} = 8{,}09Kg$

Peso dos vidros da janela de observação: 0,640Kg

Peso total da campânula = 47Kg

Flexão na viga b (tubo redondo)

$\sigma adm = \sigma esc / FS$
$\sigma adm = 2400 / 4$
$\sigma adm = 6MKgf/m^2$

$\sigma f = M.C/I$
$\sigma f = 21{,}15 \cdot 44{,}125 \cdot 10^{-3} / 0{,}7854 (44{,}125 \cdot 10^{-3} - 40{,}125 \cdot 10^{-3})$
$\sigma f = 297{,}06\ Kgf/cm^2$

$f = Ml^2/2EI$
$f = 21{,}15 \cdot 1{,}2^2 / 2 \cdot 2 \cdot 200000 \cdot 10^4\ 3{,}1416 \cdot 10^{-3}$
$f = 2{,}203 \cdot 10^{-4}$ mm (flecha)

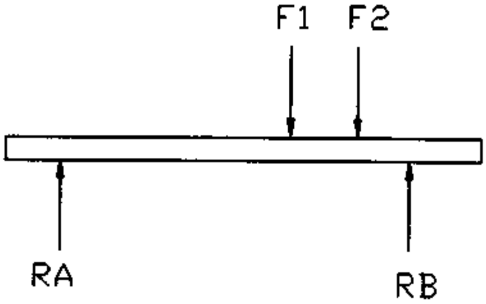
Flexão na viga a (viga em U)

$\sigma adm = \sigma esc / FS$
$\sigma adm = 2400 / 4$
$\sigma adm = 6MKgf/m^2$

$\sigma f = M.C/I$
$\sigma f = 21{,}15 \cdot 28{,}02 \cdot 10^{-3} / 9{,}977 \cdot 10^{-8}$
$\sigma f = 5{,}939\ M\ Kgf/m^2$

$f = Pl^3/3EI$
$f = 47 \cdot 0{,}450^3 / 3 \cdot 2 \cdot 200000 \cdot 10^4 \cdot 9{,}977 \cdot 10^{-8}$
$f = 0{,}6504$ mm

4.4.3 - Dimensionamento da mesa:



F1 = Σ pesos da campânula, colar de flanges, válvula gaveta, redutor e bomba turbomolecular

F1 = 125,8 Kg
F2 = peso do dispositivo de levantamento
F2 = 24,68 Kg

Determinação das reações nos apoios:

$\Sigma MA = 0$
$- F1 \cdot 740 - F2 \cdot 1140 + RB \cdot 1180 = 0$
RB = 102,73 Kgf

$\Sigma Fy = 0$
$RA - F1 - F2 + RB = 0$
RA = 47,75 Kgf

Cálculo da flecha na mesa:

$ymáx = F \cdot d\,(4d^2 - 3L^2) / 24EI$
$ymáx = 125{,}8 \cdot 850\,(4 \cdot 850^2 - 3 \cdot 1200^2) \cdot 12 / (24 \cdot 2 \cdot 10^8 \cdot 20^4)$
ymáx = 0,002 mm

5- RESULTADOS ESPERADOS

Conforme mencionado no item 2 deste relatório espera-se que a Estação Multi-Uso para Testes Vácuo-Térmicos possa dar suporte ao Laboratório Vácuo-Térmico do LIT na realização de testes em materiais que apresentem taxas de degaseificação alta ou desconhecida ou em materiais cujo comportamento térmico sob vácuo não é perfeitamente definido. Através destes testes será possível, entre outras coisas, desenvolver trabalhos tais como de coleta de parâmetros para qualificação prévia de materiais que poderão integrar sistemas espaciais ou para estudos de melhoria nas técnicas de simulação espacial.

Convém mencionar que, referente a parte técnica, o requisito principal do projeto é desenvolver uma estação que atenda uma grande diversidade de testes com aplicações de técnicas simples, práticas e de baixo custo, porém com resultados precisos.

Deseja-se que até dezembro/96 o projeto da Estação Multi-Uso esteja concluído e em dezembro/97 a Estação Multi-Uso esteja completamente operacional, viabilizando assim a execução dos testes acima mencionados.

Por problemas diversos não será possível dar continuidade e concluir a fase final do projeto através desta Bolsa do PIBIC. Entretanto, o Laboratório Termo-Vácuo do LIT mostrou-se bastante interessado em concluí-lo dentro do cronograma definido acima, e para tanto já busca outros recursos de modo que o andamento do projeto não está prejudicado.

6 - CONCLUSÕES

Com base nos estudos realizados conclui-se que para aplicações espaciais é extremamente importante que se tenha materiais que apresentem uma taxa de degaseificação baixa, pois as moléculas liberadas podem eventualmente se depositar sobre superfícies de satélites artificiais, veículos ou experimentos espaciais, e dependendo da quantidade de moléculas depositadas pode-se comprometer o funcionamento do sistema espacial e a confiabilidade dos dados coletados.

A deposição de moléculas em lentes de câmeras embarcadas em um sistema espacial, pode gerar distorções das imagens recebidas pela mesma prejudicando a qualidade dos resultados. No caso de deposição em células solares ocorre uma redução da eficiência das células, ou seja, as células passam a captar menos luz que posteriormente é transformada em energia elétrica para alimentar o satélite.

Pode ocorrer ainda alterações das propriedades termo-ópticas de superfícies, ou seja, alteram-se os valores de emissividade e absortividade, que são propriedades relacionadas com a quantidade de energia térmica emitida ou absorvida de uma superfície, podendo assim prejudicar o balanço de energia térmica entre o equipamento de vôo e o ambiente espacial.

Um outro fator que não está associado à degaseificação mas sim ao vácuo e pode comprometer o sistema espacial é a falta de convecção de ar que dificulta a troca térmica e pode gerar gradientes de temperatura relativamente altos ou até mesmo superaquecimento de componentes.

Tendo em vista todo o conhecimento adquirido nas áreas de tecnologia de vácuo e de simulação espacial e considerando-se ainda a oportunidade de participar diretamente do projeto de uma câmara de vácuo e estar em contato com equipamentos de alta tecnologia, pode-se dizer que foram válidos toda a dedicação e desempenho dispensados ao projeto.

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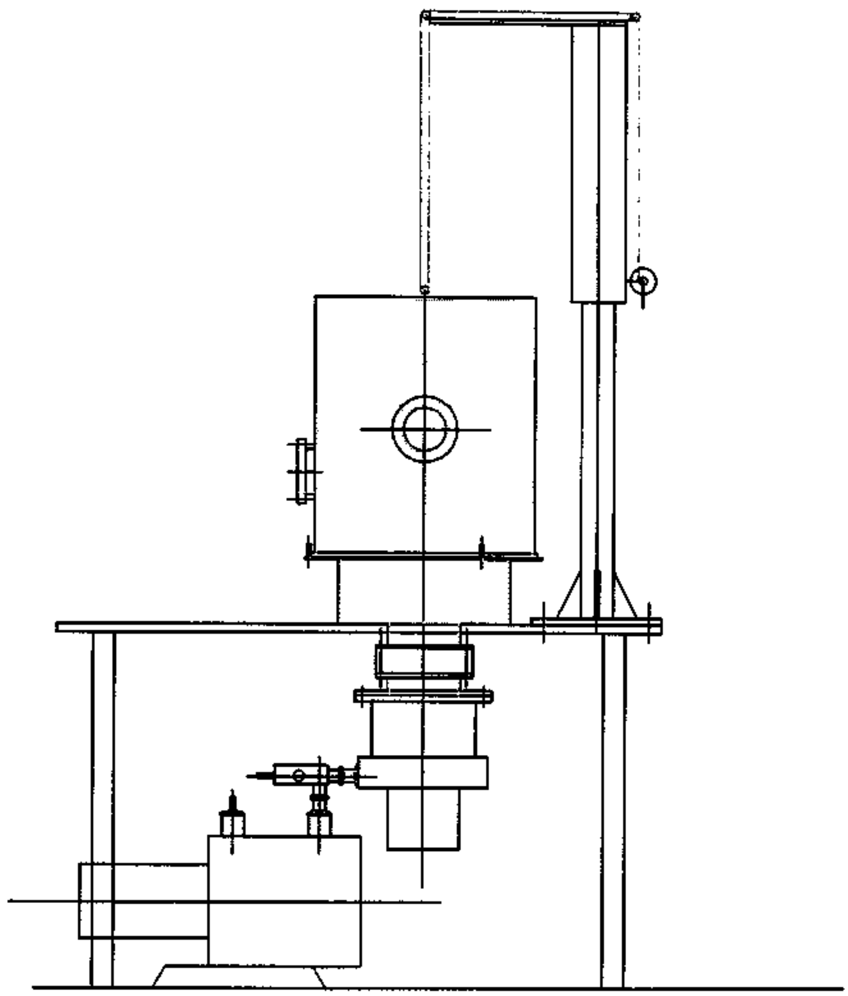
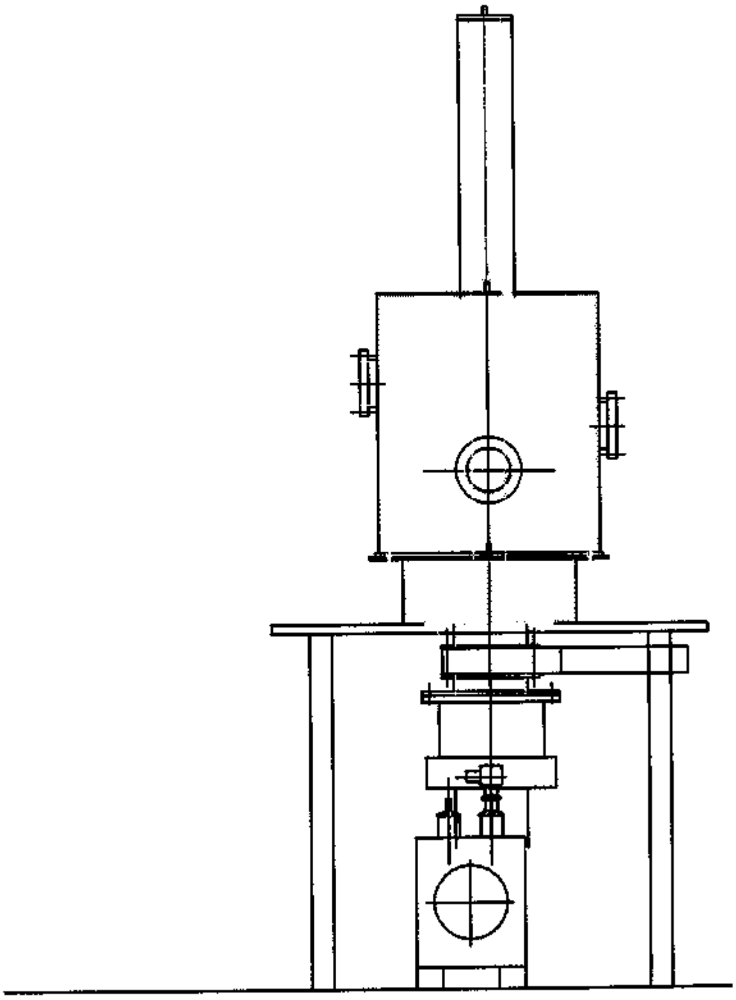
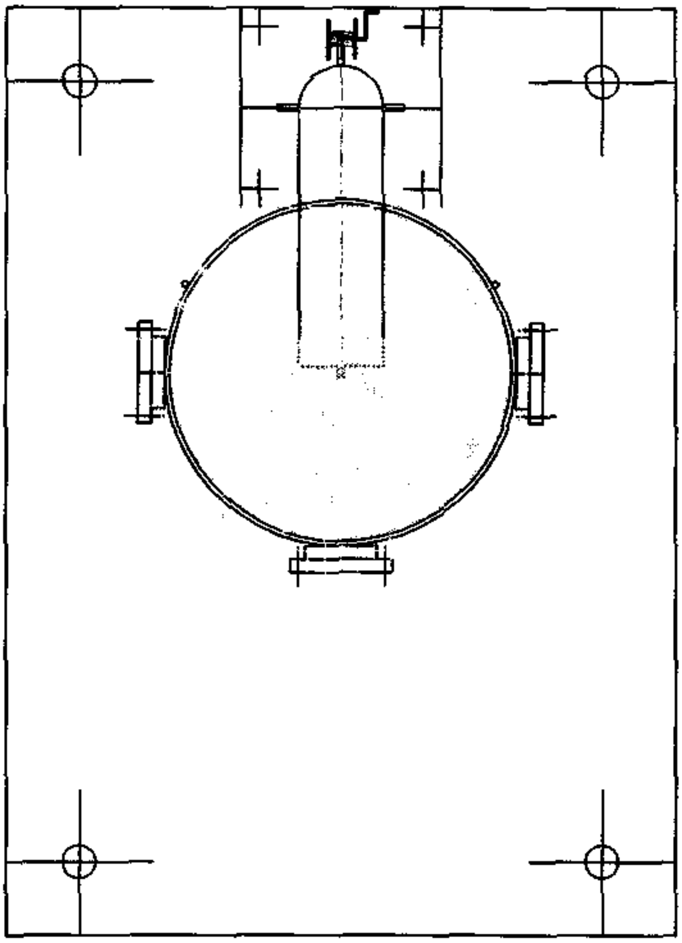
APÊNDICES







pronoun to say, for example, "From these results I conclude that . . ."

Data Presentation

Because most technical reports rely on figures and tables for the presentation of data, the form and quality of the figures and tables are important in establishing the style and readability of the report. Good judgment should be used in selecting both the data to be presented and the method of presentation. Use only figures and tables that add to the value of your report. Present the data as simply and straightforwardly as possible so that your readers can easily grasp the significant points. Present data in the text, or in a figure, or in a table--but never in more than one way.

Before beginning to write the report, carefully select the data to include. Most carefully prepared programs yield more data than are needed to support the conclusions. Including all your data in the report is unnecessary. Use only data that are directly pertinent to your conclusions, and do not try to impress readers with how much data you have collected. Quantity is no substitute for quality in presenting technical results.

Once you have selected the data to be included in your report, decide how they can best be presented. Should they be tabulated or plotted? To answer this question, consider your readers' needs. Do they need to know exact values? If so, tabulate your results. If relative trends are more important, use graphs. Both the figures and tables should be as self-explanatory as possible and arranged logically to tell the main points of your story without reference to the text.

Figures

The figures used in technical reports generally are of three types --graphs, drawings, and photographs. Figures are numbered with Arabic numerals in the order of their mention, unless the mention is clearly incidental. In the final report they are either inserted in the text near (preferably following) their first mention or grouped together at the back. Sketches are lettered consecutively ((a), (b), (c), etc.) if they are referred to more than once. Under no circumstances should the arrangement of black and white figures or the parts of one figure be out of sequence. Figures arranged in a group are in sequence from top to bottom or from left to right. Exceptions are sometimes made for color figures to reduce the number of pages printed in color.

Prepare figures with consideration for their appearance in the final printed document. The size of the printed figure including the legend (title) cannot exceed the dimensions of the report image area (7 1/8 by 9 1/8 in. in NASA reports). Within these limits various sizes, proportions, and arrangements of figures are possible. (A large, complex figure may be reproduced on facing pages.)

All figures must have legends; if a figure has parts ((a), (b), (c), etc.), it must have corresponding sublegends. Use similar wording in the legends of related figures. After you have assembled the rough draft of the report, thumb through the figures and tables, reading merely the title of each to make certain that the format and the nomenclature are consistent. Conditions applying to the entire figure or to a part are normally stated as part of the legend or sublegend. But when the same conditions apply, for example, to every graph in a report, they are best stated once in the text.

Graphs

Graphs should be clear and simple with as few data curves as possible. It is usually best to have no more than six types of lines or data points on a graph--four is better. Try to avoid interlaced or unrelated

PILOT PROJECT FOR THE ESTABLISHMENT OF A DEVELOPMENT PROCESS FOR FUTURE SPACE SYSTEMS AT INPE

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ABSTRACT

This work presents a customization of the European Cooperation for Space Standardization (ECSS) standards for defining a development process for the ground segment of the FBM project. The FBM project consists of a scientific/technological space mission developed in cooperation between Brazil and France. In this project, the development of the ground control system and the in-flight satellite operation are under INPE responsibility. For the in-house developed ground systems, a process that establishes project phases, milestones, activities, input and the output documents/products to be generated at each phase, was defined, taking into account the existing resources and background at INPE. This paper focuses on the aspects of requirements management, configuration management, verification and validation . Moreover, it points out the COTS tools adopted for assisting in the product quality assurance activities. The process, defined in the context of the FBM ground segment, is being considered as a pilot project . It is expected that, as a consequence of its good results, in the long term, it will be adopted in all future missions.

Keywords: ground segment, ECSS standard, development process.

1. INTRODUCTION

The French-Brazilian Micro-satellite (FBM) project consists of a space mission developed by Brazil and France that aims the developing, launching and operating of a scientific/technological micro-satellite carrying experiments from both countries. In this cooperative project between INPE and CNES, the Ground Segment, among other tasks, is under INPE's responsibility.

Due to the increasing pressure to reduce costs and the complexity of the systems, the adoption of a well established process for the systems development is more and more necessary. In this context, the development team was led to formalize a process based on the ECSS standards [1].

Nevertheless, the extensive coverage of the ECSS standards and the tight schedule has led the process to be not fully compliant with the standard and to be incrementally implemented. Its first version covers the Ground Segment Engineering general context and focuses on the needs for software systems development, as most of the ground systems are software intensive.

The process comprises a Ground System software life cycle nested to the Ground Segment life cycle. The phases, milestones and the input/output criteria characterize the life cycle at the different levels of the ground segment decomposition, as shown in section 2.

In order to assure the quality of the systems to be developed, the process is supported by the following areas: requirements management, configuration management and verification & validation (V&V), which are presented in sections 3, 4 and 5 respectively. Conclusion and remarks are drawn in section 6.

On the other hand, do not condense reports at the expense of your readers' understanding. Give enough information to enable them to understand clearly *what* you are describing and *why* you are describing it. Include enough background information to make the context clear. Do not assume that they will remember details of a previous report--or have even read it. Include all details needed to understand the current report. In short, make your reports brief but comprehensible.

Continuity

Reports should tell a complete story as logically and interestingly as possible. This requires continuity between succeeding sentences, paragraphs, and sections and between the written text and the figures and tables. Transitional words, phrases, sentences, or even paragraphs may be needed to lead your readers through the story. But overusing transitions can slow the pace of your narrative.

Carefully choose the places at which you refer to figures and tables to limit distraction. Making these references at the beginning or end of a discussion is usually preferable.

Objectivity

Technical reports should be objective and show restraint. Be honest with your readers. They will become suspicious if they detect hidden meanings or any type of subterfuge, and you will then have little chance of convincing them of your conclusions. They expect you to evaluate the data honestly. Do not try to hide deficiencies in your research. No technical report is better than the research on which it is based. Tell your readers frankly what your assumptions were, what your probable errors are, and what you may not understand about the results.

In addition to being honest, be tactful. If you are faced with the problem of presenting technical results that may conflict with previous results or with the personal prejudices of some readers, refrain from making dogmatic statements and avoid sounding egotistical. Your readers will be persuaded by facts, but they may become irritated if you attempt to impress them with your cleverness or to claim credit for accomplishments. Write to *express*, not to *impress*.

Writing Style

Technical writers usually use a more formal writing style than do nontechnical writers. A degree of formality is required because the personal style of a technical writer must be secondary to the clear and objective transmission of information. Any injection of personality that obscures the exact meaning is undesirable. But this does not mean that technical writing has to be dull and rigidly stereotyped. All writers should strive to make their writing enjoyable to read. Therefore attempt to develop a writing style that is both clear and interesting.

This section includes some specific suggestions for developing and improving your writing style. For additional suggestions read some good books on technical report writing and grammar (e.g., refs. 1 to 6).

Writing Naturally

Imperative in developing a good writing style is writing naturally. Many technical reports are stilted and overly formal, examples of the "Official Style" discussed by Lanham (ref. 4). Authors usually do not speak that way, but they feel that technical reports must be written in that style. A stilted style is difficult to read and detracts from the contents.

2. THE DEVELOPMENT PROCESS

The process was based mainly on the ECSS standards which has being a very good reference for the general understanding of the particularities of the space systems. Besides that, it provides a framework to define and implement a space project.

The decomposition of the space system in hierarchical levels established in the Development Process of the FBM is illustrated in Figure 1.

The systems of a space mission are classically broken into Space and Ground Segments. The Space Segment is related to the conception, design, production, integration, verification and validation of all spacecraft systems, while the Ground Segment is in charge of preparing the environment, designing, implementing, integrating, verifying and validating the systems to remotely monitor and control the spacecraft as well as to explore and disseminate the mission data.

The systems comprising the Ground Segment are named **Ground Systems** and the software and the hardware products composing each Ground System are referred as **subsystems** or **elements**.

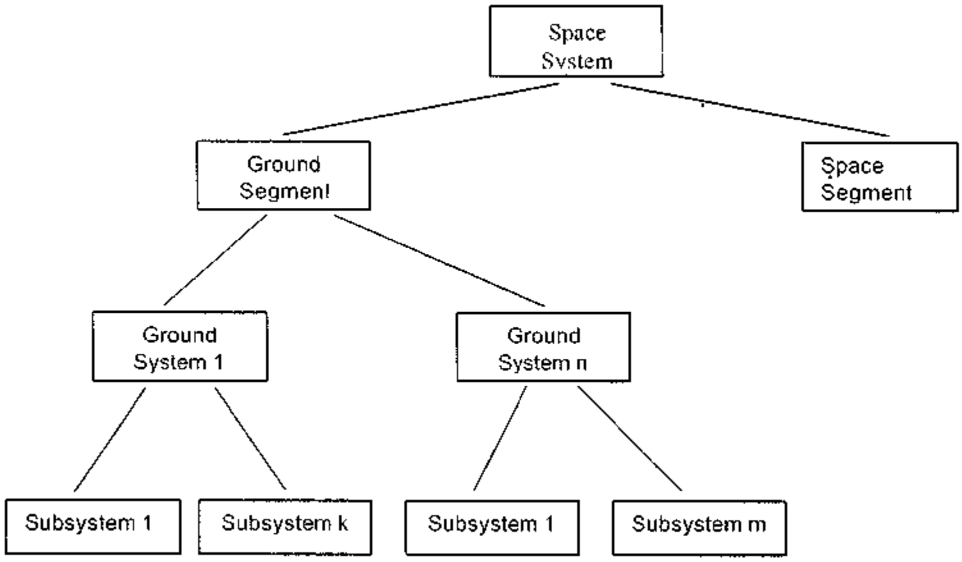

Figure 1 – Diagram of Hierarchical Levels of a FBM Space System

The ground systems of the FBM project are the Control Center System, the Natal Ground Station System, the Brazilian Mission Center System, the French Mission Center System, the Satellite Model Data Base and the Ground Communication Network. The system testing tools, viz. the Satellite Simulator and the Suitcase are also at the ground system level.

The ground segment project comprises the following five main activities, illustrated in figure 2: Ground Systems Development; Operations Preparation; Ground Segment Integration; Technical Validation and Operational Validation. These activities are conducted over two parallel main domains, the Ground Systems Development and the Operations Preparation and are followed by the verification and validation activities [3].

The Operations Preparation activities include the generation of a set of documents viz., Mission Operation Concept (MOC), Operational Validation Plan, Operators Training Plan, Flight Operations Plan (FOP), Ground Operations Plan (GOP) and Ground Segment Operations Schedule. The activity of training the satellite operation team also comprise the Operation Preparation.

To avoid a stilted style, write in a way that comes easily, using words and phrases that come naturally to you. Do not try to impress readers with your vocabulary, but be certain that the words you use convey your exact meaning. Your readers will be interested in what you have to say and not in how eloquently you say it. Avoid long, complicated terms if shorter and more familiar ones are available. But be careful not to use jargon because it may be misinterpreted.

Guiding the Reader

To achieve clarity and continuity in a report, you must carefully direct your readers' attention throughout the report. Many successful writers do this by using the three classic principles of presentation:

1. Tell readers what you plan to tell them (Introduction).
2. Then tell them (main text).
3. Finally tell them what you told them (Summary of Results or Conclusions).

State your purpose or objective clearly and follow it with a concise description of the method you will use in presenting the subsequent discussion. Then proceed with your presentation, making certain that it is consistent in every respect with your plan. Finally summarize your conclusions and recommendations.

Getting to the Point

Technical reports are not mystery novels; get to the point as directly as possible. Do not lead your readers in and out of blind alleys before taking them to the final destination. Omit information that does not directly relate to the conclusions. Remember, readers are interested primarily in conclusions and supporting evidence.

If you must include some information or discussion that may be of interest but is not directly pertinent to your conclusions, put it in an appendix. Using an appendix allows you to bring up points that may be of interest to some of your readers without distracting the reader who is interested solely in your conclusions.

Emphasizing Major Ideas

Because the purpose of technical reports is to transmit ideas, emphasize your major ideas so that they cannot be missed. To do this, clearly subordinate any supporting information to the major ideas. The report outline is particularly useful here because it establishes the major and supporting points for each section of the report.

The statement of your opinions is an instance where the use of the first person is desirable. For example, if you follow the presentation of some specific results with "It is believed that . . .," your readers cannot be sure if this is your opinion or a generally accepted belief. To avoid this confusion, use the first-person

Separating Fact From Opinion

The development of each Ground System includes the activities of project, production, integration and test. If the Ground System is broken into subsystems, then each subsystem, hardware and/or software, has also the activities of project, production, integration and test.

When the ground systems are ready and accepted, the Ground Segment Integration phase starts. Following this phase, the Technical Validation is executed, including the integration between ground and space segments. The Operational Validation closes the activities of the Ground Segment development, meaning that all ground systems are ready to assume the responsibility of the satellite operation.

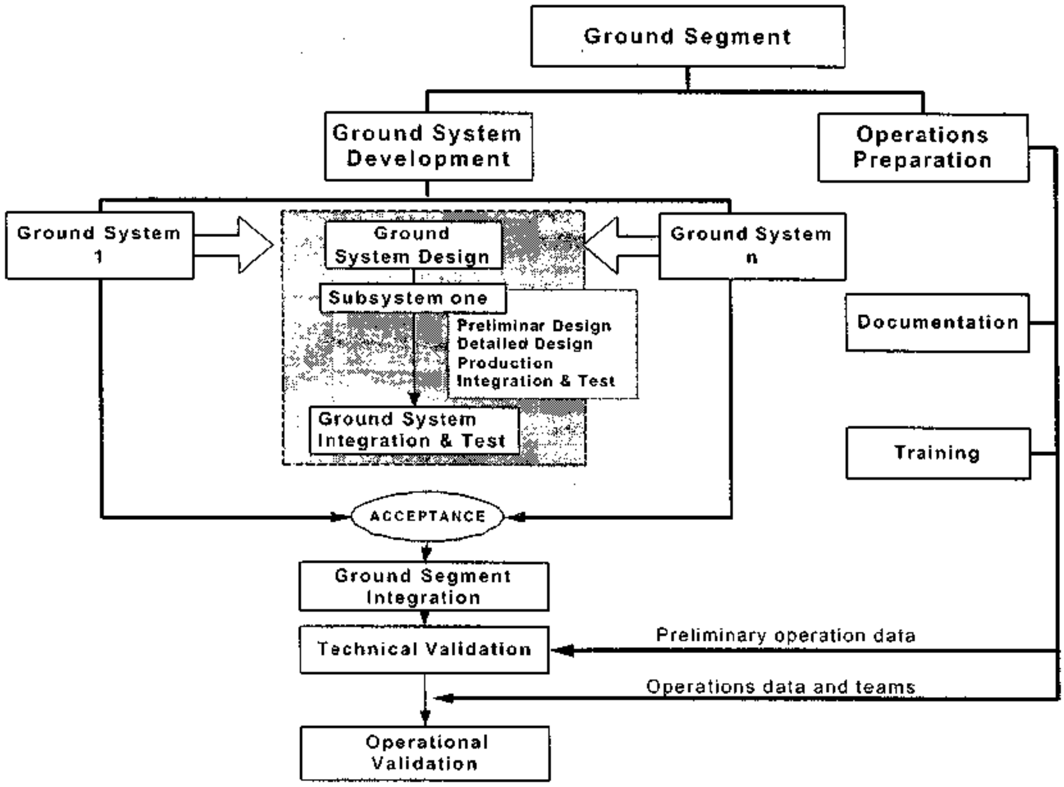

Figure 2 – Ground Segment Development Activities

2.1. PHASES AND ACTIVITIES

The top level phases of the Ground Segment Development Process are the commonly designated mission phases, e.g., 0/ A, B, C, D, from conception to validation. The operation and maintenance phases, E and F respectively, are not considered in the present process. Table 1 summarizes the Ground Segment activities and reviews that should be performed during the mission development. One phase begins only after the success of a formal review of the previous phase. The development phases of a intensive Ground System software, mainly, I-a, I-b, II, III-a, III-b, IV and the respective reviews, that occur at the end of the respective phase, are summarized in Table 2. The output of phases I-a, I-b, II, III-a and the results of their respective reviews, GSPDR, SRR, SPDR and SCDR are the inputs to the Ground Segment Critical Design Review, the GCDR. Figure 3 presents an overview of all phases and reviews from both levels: Ground Segment and Ground System, highlighting the overlaps among them. It may be observed that to start the phase D2 the ground systems must be already validated and accepted, then they are ready for the Ground Segment integration and tests. In the FBM software development process some additional phases and reviews were included. Figure 4 shows a

On the other hand, do not condense reports at the expense of your readers' understanding. Give enough information to enable them to understand clearly *what* you are describing and *why* you are describing it. Include enough background information to make the context clear. Do not assume that they will remember details of a previous report--or have even read it. Include all details needed to understand the current report. In short, make your reports brief but comprehensible.

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Reports should tell a complete story as logically and interestingly as possible. This requires continuity between succeeding sentences, paragraphs, and sections and between the written text and the figures and tables. Transitional words, phrases, sentences, or even paragraphs may be needed to lead your readers through the story. But overusing transitions can slow the pace of your narrative.

Carefully choose the places at which you refer to figures and tables to limit distraction. Making these references at the beginning or end of a discussion is usually preferable.

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Technical reports should be objective and show restraint. Be honest with your readers. They will become suspicious if they detect hidden meanings or any type of subterfuge, and you will then have little chance of convincing them of your conclusions. They expect you to evaluate the data honestly. Do not try to hide deficiencies in your research. No technical report is better than the research on which it is based. Tell your readers frankly what your assumptions were, what your probable errors are, and what you may not understand about the results.

In addition to being honest, be tactful. If you are faced with the problem of presenting technical results that may conflict with previous results or with the personal prejudices of some readers, refrain from making dogmatic statements and avoid sounding egotistical. Your readers will be persuaded by facts, but they may become irritated if you attempt to impress them with your cleverness or to claim credit for accomplishments. Write to *express*, not to *impress*.

Writing Style

Technical writers usually use a more formal writing style than do nontechnical writers. A degree of formality is required because the personal style of a technical writer must be secondary to the clear and objective transmission of information. Any injection of personality that obscures the exact meaning is undesirable. But this does not mean that technical writing has to be dull and rigidly stereotyped. All writers should strive to make their writing enjoyable to read. Therefore attempt to develop a writing style that is both clear and interesting.

This section includes some specific suggestions for developing and improving your writing style. For additional suggestions read some good books on technical report writing and grammar (e.g., refs. 1 to 6).

Writing Naturally

Imperative in developing a good writing style is writing naturally. Many technical reports are stilted and overly formal, examples of the "Official Style" discussed by Lanham (ref. 4). Authors usually do not speak that way, but they feel that technical reports must be written in that style. A stilted style is difficult to read and detracts from the contents.

parallel between the software development phases and reviews proposed by the ECSS standards [4] and those established for FBM software development.

Table 1 – Ground Segment Activities/Reviews of the Mission Phases

Phase / Review	Description	Activities /Review objective
0/A	Mission analysis and feasibility	-Identify the characteristics, constraints, concepts and evaluate the mission feasibility of Ground Segment and satellite operations. -Define preliminary space to ground interface -Define preliminary Ground Segment architecture
GRR	**Ground Segment Requirements Review**	Select a preliminary Ground. Segment baseline
B	Ground Segment Preliminary Design. Operation concepts consolidation.	-Define the Ground Segment requirements and its baseline, -Consolidate the operations concepts. -Define the ground systems and the system testing tools
GPDR	**Ground Segment Preliminary Design Review**	Approve the Ground Segment baseline and select the main suppliers.
C	Ground Segment Detailed Design Operations Preliminary Plans.	-Identify subsystems comprising each ground system - Prepare a initial version of Flight Operation Plan, operation team training Plan and operational validation document.
GCDR	**Ground Segment Critical Design Review**	- Approve specification, organization, planning, costs and quality of the Ground Segment Detailed Design - Check compatibility of external and internal interfaces - Check conformance with Ground systems
D	Production, Verification and Validation (V&V) of the Ground Systems	
D1	Production	- Implement the subsystems - Integrate & test each Ground System
D2	Ground Segment Integration Preliminary version of operational procedures and mission data Technical V&V	- Integrate Ground Segment - Populate the Satellite Model Data Base - Validate operational procedures - Execute Technical V&V
GTVVR	**Ground Segment Technical Verification & Validation Review**	- Assure that Ground Segment conforms to its specification
D3	Operation team training Conclusion of the Flight Operation Plan Operational Validation	- Conclude the training plan - Train operating team - Conclude the FOP & operation schedules - Validate all Ground Segment: systems and operations
OVR	**Operational Validation Review**	- Assure the full readiness of the Ground Segment for in-orbit satellite operation.

Table 2 – Ground Systems and Software Products Phases/Activities/Reviews

Main	Software		Activities

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Chapter 2--Report Style

> There is no satisfactory explanation of style, no infallible guide to good writing, no assurance that a person who thinks clearly will be able to write clearly, no key that unlocks a door, no inflexible rules by which the young writer may shape his course. He will often find himself steering by stars that are disturbingly in motion.

As this quotation from Strunk and White (ref. 1) indicates, this chapter deals with an elusive but important aspect of report writing--style. Although difficult to define, style establishes the readability of reports. In effect, the style of the report sells the report. If your style of writing and presentation is not acceptable to your intended readers, they may not read your report.

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Requirements of Reports

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Clarity

The purpose of a technical report is to transmit conclusions and their supporting evidence. To do this, your report must convey your *exact* meaning to the reader. The text must be clear and unambiguous, mathematical symbols must be fully defined, and the figures and tables must be easily understood.

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Phase/ Review	phase/ Review	Description	/Review objective
C	I-a	Ground System Preliminary Design	- Analyze system requirements, - Decompose the system in software subsystems - Define the interfaces among the software subsystems
	GSPDR	**Ground System Preliminary Design Review**	
	I-b	Requirements definition of software subsystem	- Define the subsystem requirements from the user's point of view
	SRR	**Subsystem Requirement Review**	
	II	Preliminary Design of Software Subsystem	- Analyze the requirements - Design the high level architecture (logical and physical) - Perform the Data Base logical design - Define the Interfaces among the modules
GSCDR	SPDR	**Preliminary Design Review of Subsystem**	
D1	III-a	Detailed Design Review of Software Subsystem	- Design each module
	SCDR	**Critical Design Review of Subsystem**	
	III-b	Production	- Perform the coding - Test the software units - Integrate and test the software subsystems - Apply the acceptance test to the subsystem
	SATR	**Subsystem Acceptance Test Review**	
	IV	Ground System Integration and Test	- Integrate the ground system - Technically Validate the ground system - Apply the acceptance test on the ground system
	GSVR	**Ground System Technical Validation Review**	
	GSAR	**Ground System Acceptance Review**	

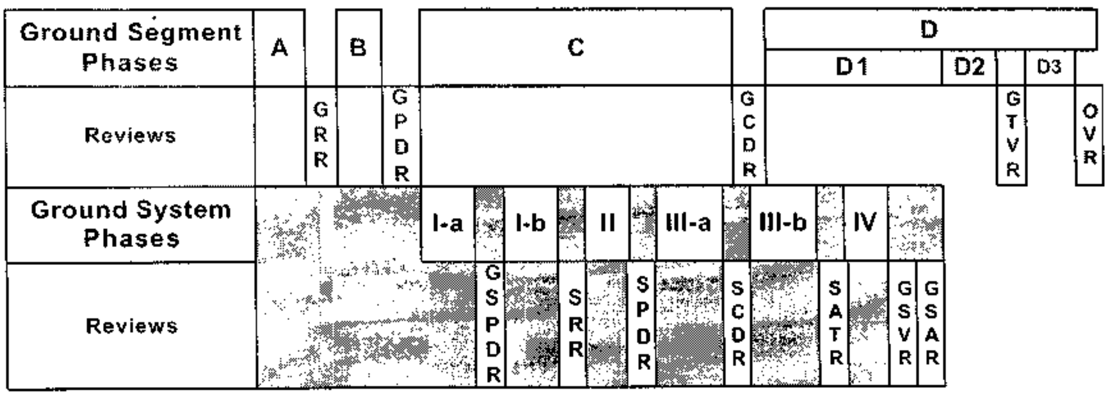

Figure 3 - Ground Segment and Ground System Phases/Reviews

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ECSS Software Phases	Requirements Engineering						Design Engineering				Software V&V		
Reviews				SRR		PDR				CDR		QR	AR
Ground System Phases	I-a		I-b		II		III-a		III-b		IV		
Reviews		GSPDR		SRR		SPDR		SCDR		SATR		GSVR	GSAR

Figure 4 - Ground System and ECSS Software phases

3. REQUIREMENTS MANAGEMENT

The ground segment development success is closely related to insuring that the generated systems comply with the mission requirements. Due to this fact the requirements management is invaluable to support the Quality Assurance of the generated products.

In order to correctly generate a system it is necessary to insure, at least, that:

- each requirement of a high level component is met by a low level component,
- during the design of a component each requirement is addressed to one sub-level component,
- each component is originated from at least one requirement.

Moreover, the management of the relationship among the several information levels is essential to evaluate the impact (work volume) whenever changes in requirements or design are requested.

The requirements management process will be composed of three activities: requirement identification, traceability policies and requirement change management, which will be supported by the Rational RequisitePro™ tool.

The requirement identification consists of associating one unique identification to each requirement and to each component generated during the several design levels (systems, subsystems, elements).

The requirements traceability will be implemented from the Ground Segment Level to the software elements level. The whole process was structured to support traceability in horizontal and vertical levels. Vertical traceability is covered between requirements from one level to the requirements of both the upper and lower levels. Horizontal traceability is covered over requirement, design components and interfaces. The traceability policies, illustrated in figure 5, shows the coverage of the following aspects: Requirements x Requirements; Requirements x Design; and Interfaces x Design.

The Requirements x Requirements traceability allows to verify that all high level requirements are covered by lower level requirements and that each lower level requirement is originated from a higher level requirement.

The Requirements x Design traceability allows to verify that all requirements are covered in the design solution and that the design solution fulfills, at least, one requirement.

The aim of the Design x Interfaces traceability is to demonstrate that all the high level interface requirements are covered in the next lower level design solution and that the design solution fulfills all the interface requirements.

Related to the requirement change management, a formal process was defined. This process is composed of: problem analysis, change impact analysis and change implementation in case of approval.

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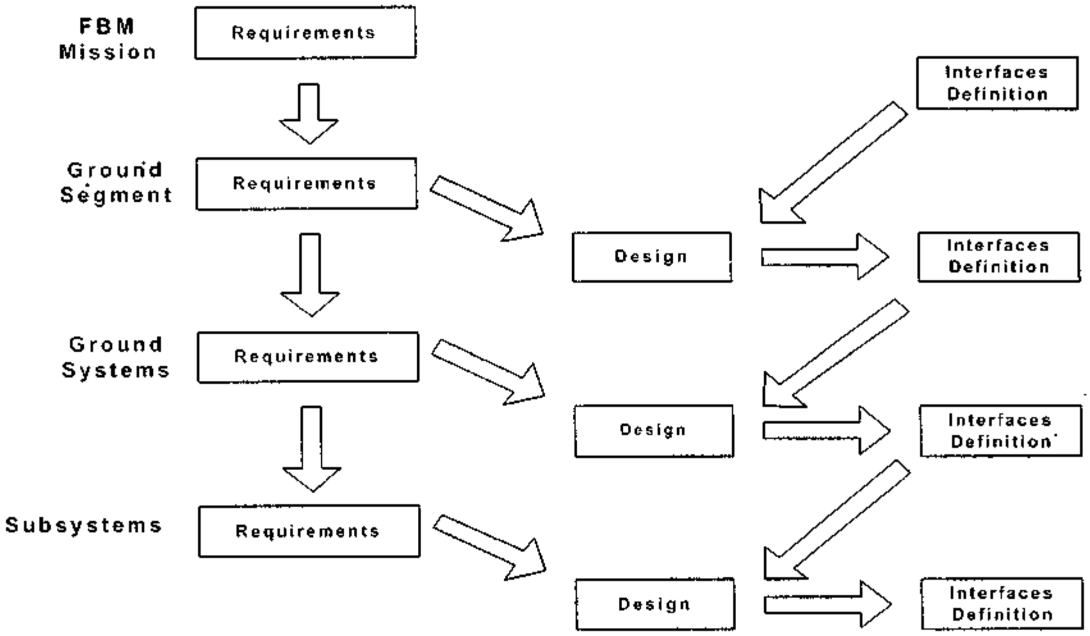

Figure 5 – Traceability levels

4. CONFIGURATION MANAGEMENT

As changes along the systems development are unavoidable, a Configuration Management process is needed to identify, manage and keep control of the product changes (softwares and documents).

The products generated at each development phase are reviewed, and, in case of approval, they are put under configuration control, at the end of that phase. Whenever a controlled product has to be modified, the following formal process will be accomplished:

- Problem identification and change request
- Change impact analysis and definition of the affected products
- Change request approval
- Change execution
- Change review
- Creation of new version of the modified products

To support the Configuration Management process of the documents (which includes the following activities: product tree creation, document version control and changes, and reviews workflow management), the Directa^{tm} tool will be used.

The software elements version control and the software products generation will be performed using the Microsoft Visual Source Safe^{tm} and Microsoft Visual C++ 6.0^{tm} tools in an integrated way.

The change impact evaluation will be performed with the aid of both the traceability matrices generated by the Rational RequisitePro^{tm} tool and the dependency tracking facilities available in Microsoft Visual Source Safe^{tm} and Microsoft Visual C++ 6.0^{tm} tools.

For ease in reading numbers of five or more digits, group them in threes from the decimal point, separated by spaces instead of commas. In a column of numbers add the space to all numbers if at least one number in the column has five or more digits to the left of the decimal point--for example,

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Otherwise close up four-digit numbers in columns.

Rough-Draft Typing

Most rough drafts are typed by the author or in the research branch or division office. When submitting your report to the Publishing Services Coordination Office, provide the diskette and a *double-spaced* hard copy. Indicate the the wordprocessing and graphics programs used, including the platforms. If the rough draft cannot be typed in your division, the Publishing Services Coordination Office will arrange for typing (see Manuscript Services). Clearly mark handwritten material, particularly equations, so that the typist will understand what is meant. Identify such symbols, as well as handwritten Greek or unusual symbols, the first time they are used. (This advice applies equally to figures and slides, especially if they will not be edited.) Writing text on every other line (double spaced) will also help the typist.

Chapter 1

Chapter 3

- Contents

5. VERIFICATION AND VALIDATION

The V&V aims at achieving the maximum reuse of the testing tools and the adoption of cost effective techniques in order to assure the required quality of the software products of the FBM Ground Segment with a minimum effort.

By *Verification* we mean to revise, inspect, test or audit a process or services and/or documents in order to evaluate if they conforms to the specified requirement [6]. And, by *Validation*, to evaluate the final product conformance to the user specified requirements [2].

The activities of the V&V process run in parallel to all phases of the development process. The process starts with the Ground Segment requirement specification and proceeds until the code lines of the subsystem software units, so it comprises different stages based on the concept of bottom-up building-blocks. In the process presented here, two verification methods will be used: reviews and tests, whereas only tests are used as the validation method.

The reviews comprise static technical analysis over all generated documents. The set of the established formal reviews, at the end of each phase, are presented in section 2. Five reviews are expected to cover the mission phases, as shown in Table 1 and, at Ground System level, seven other formal reviews are planned, as shown in Table 2.

Relative to the tests, in general there will be three kind of tests: unit, integration and acceptance or validation tests to be applied to each level of details, such as ground segment, ground system and subsystem.

The life cicle of the tests defined for the FBM Ground Segment sugests a development in "V. The planning of the tests is prepared at each phase of the development, in a top-down strategy. However, the test execution and results report are applied and generated respectively, in a bottom-up strategy.

An overview of all test phases, from the Ground Segment to the subsystem level is illustrated in Figure 6. At the left side, it is indicated the set of documents generated in one phase (baseline): GRRD, GPDRD, etc. which serve as the basis to test cases especification and planning. At the right side, the arrows indicated the produts states at the end of each phase, from compiled software units to the Ground Segment ready for in-flight operation. The minimal criterium for testing is to cover all the specified requirements for functional and performance tests, all interfaces for integration tests and all operational procedures for operational tests. The unit test corresponds to white-box test, and in which the minimal criterium will be established case by case, because of the particularities of each implementation. For object-oriented subsystems, some guidelines have being prepared based on the work presented in [5].

and Government research organizations.

Microfiche Supplements

A microfiche supplement, like a technical film or videotape supplement, can make available considerably more graphic and textual information than the basic research document. Microfiche supplements are typically used for extensive sets of tables or figures and comprehensive bibliographies.

CD Supplements

CD supplements, to document lengthy material electronically instead of in printed form, can be ordered through the Imaging Technology Center.

Miscellaneous

Computer Programs

Reports and papers should not include computer programs. Computer programs are to be distributed by the Computer Software Management and Information Center (COSMIC), a NASA facility at the University of Georgia. In order to ensure and expedite the availability of a computer program to U.S. users, obtain a LEW-number from the Technology Utilization (TU) Office before submitting the publication to Publishing Services for processing. (Reference the LEW number in the report.) The Technology Utilization Office will prepare a Tech Brief and send it and the program to COSMIC.

Trade Names

Use of trade names is discouraged because NASA considers it improper to advertise, endorse, or criticize commercial products in its publications. Use generic names whenever possible. Trade names may be used if their use is the only way to specify material or equipment that is necessary to reproduce the results. The first appearance of a trade name in the text must be accompanied by the name of its registered owner (e.g., International Nickel Co., Inc., IN738). But the symbol for a registered trademark (an R inside a superscript circle) is not used. Those reports using trade names must include a trade name disclaimer:

> Trade names or manufacturers' names are used in this report for identification only. This usage does not constitute an official endorsement, either expressed or implied, by the National Aeronautics and Space Administration.

The disclaimer is printed on the inside front cover of a Technical Memorandum or on the back of the title page of a Technical Paper.

Spelling

The authorities for spelling in Glenn reports are the NASA Thesaurus (ref. 8 or online version), Webster's New Collegiate Dictionary (ref. 9), and the Government Printing Office (GPO) Style Manual (ref. 10). The GPO Style Manual is also a guide for punctuation, compounding words, and capitalization.

Numerals

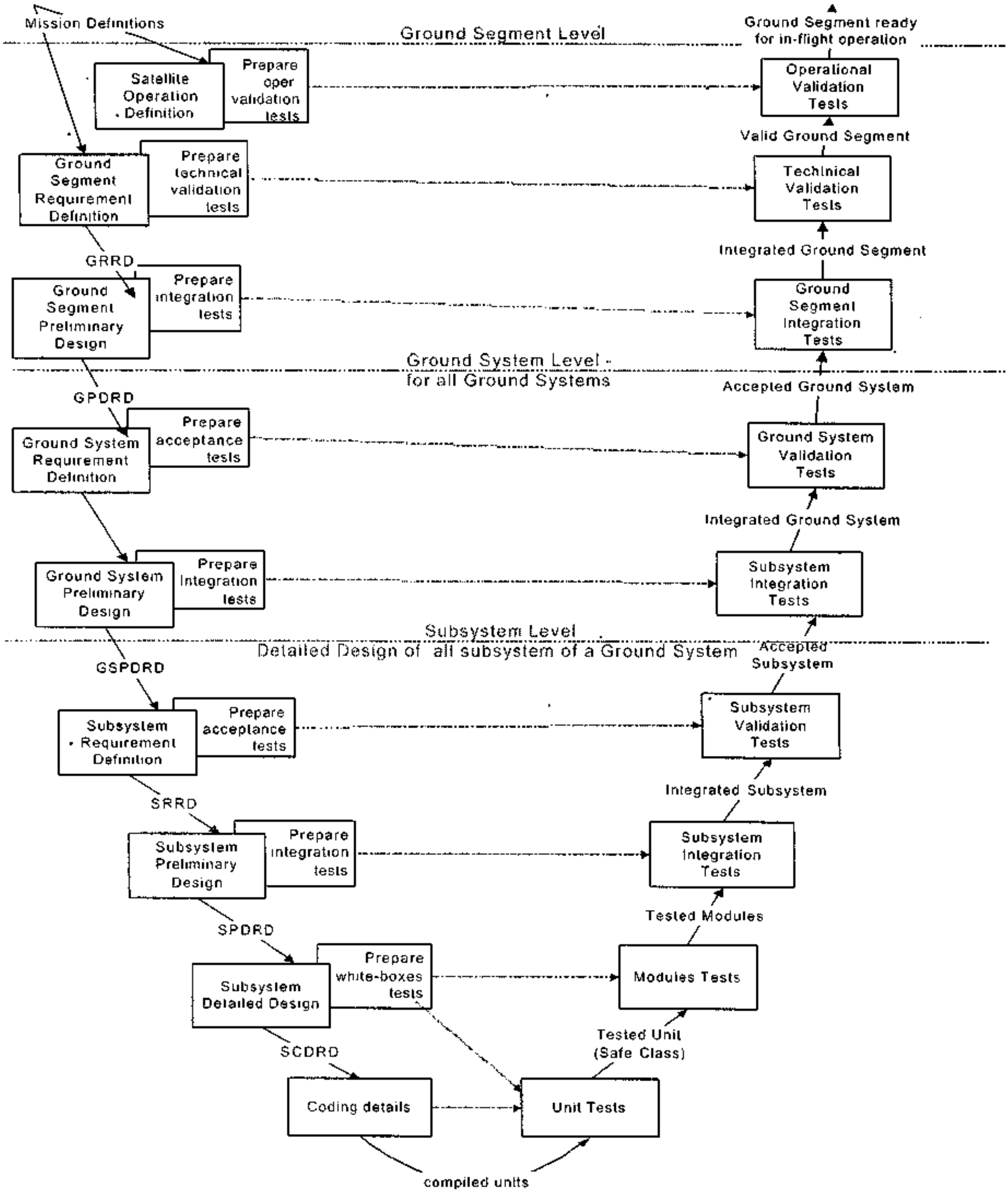

Figure 6 - Overview of the Ground Segment Test Phases

than the glossy print.

If your photographs are Polaroid prints, have negatives and additional prints made before submitting them for use in a report, for slides, etc. You are then protected in case of damage or loss, and prints are readily available for additional uses.

Include some object or scale in the photograph to help your readers judge the size of the objects shown. For photomicrographs and electron micrographs, use a scale instead of stating the magnification:

1 μm

(The size of photographs is often changed in reproduction, rendering the magnification meaningless.)

Tables

Tables are often included in technical reports to present data in an exact, highly concentrated form. But because tabulated data are so concentrated, many readers have difficulty grasping their significance. Tables are therefore the least preferred method of transmitting results to readers and should be used only when absolutely necessary. When you use tables, make them as brief and simple as possible. Otherwise your readers may not bother studying the detailed columns of figures, and you will have wasted your time in presenting the data. "Whenever a table, or columns within a table, can readily be put into words, do it" (ref. 2).

Tables are numbered in the order of their mention, in Roman numerals except when a report contains 20 or more tables. Then Arabic numerals are used. Similar data at different conditions are organized into parts ((a), (b), (c), etc.) of the same table with subtitles. Numbered tables must have titles.

Present tabulated material in an organized manner. Like elements should read *down* not across. Variables are usually given in columns topped by boxheads, with the constants given in the first, or stub, column. Boxheads should be brief; if necessary, they may be amplified by footnotes. Boxheads usually contain a word description of a concept or quantity, its symbol, and its unit, separated by commas; symbols must be defined when they are used. Arrange tabulated data in a logical order that your readers can easily recognize. Usually this arrangement is an ascending or descending order of value for the prime parameter. The order is necessary to clarify trends. You can also help your readers see relations and comparisons of data by carefully wording the boxheads and the stub column. Put items to be compared in adjacent columns. Generally numbers in columns are more easily compared than numbers in rows. Another type of table is the leaderwork table, in which dissimilar data are listed in rows with leader dots connecting each parameter with the corresponding value.

Give conditions that apply to an entire table in a headnote. Indicate footnote citations by lower-case letters (superscripts) ordered across the table from left to right and top to bottom.

Technical Film or Videotape Supplements

Where data can be more efficiently presented or concepts explained through motion pictures, consider the use of a technical film or videotape supplement to your report. For expert production assistance consult the Imaging Technology Center's video department. These films and videotapes are described in a catalog (ref. 7) and made available on loan for nonprofit, noncommercial screening. (A catalog of recent videos is available on the WWW.) Many requests are received from universities, industrial firms,

6. CONCLUSION

During the definition of the FBM Ground Segment development process it was noticed that despite the ECSS standards provide a good orientation and allow to establish a development culture in the team, they are not able to be directly used and a lot of work is necessary to tailor them.

Due this difficult, a minimal development process was established for the FBM Ground Segment products quality assurance, respecting the Mission schedule and costs. This process comprises the definition of a Ground Segment development life cycle. For each development process phase was defined the inputs, tasks and outputs based on a customer-supplier relationship. This process is supported by requirements management, configuration management and V&V activities.

The process, defined in the context of the FBM ground segment, is being considered as a pilot project. It is expected that, as a consequence of its good results, in the long term, it will be adopted in future missions. New areas will be incorporated along the time, gradually incrementing the process, respecting the team culture and feedback. Future improvement are envisioned in the areas such as: metrics and process management.

ACKNOWLEDGEMENT

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curves. As few words (labels) as possible should be inserted directly on the figure. Equations should be placed in the text, lengthy tabular material should be presented in a separate numbered table, and explanations and conditions should be added to the legends or placed in the text. (You can contact the Publishing Services Coordination Office to arrange to have the Graphics group prepare or adapt your figures.)

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Do not use the symbols + and x on figures with grid, and avoid solid or partly solid symbols if symbols overlap. The curves and data points may be identified by keys or labels. Keys are preferred when several curves must be distinguished or when several conditions are associated with each curve. Keys generally follow the format for tabular material and should be consistent throughout a set of figures.

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