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(6) RECENT ADVANCES IN AERONAUTICAL AND SPACE MEDICINE

Edited by

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Papers presented and Discussions held at the Aerospace Medical Panel's Specialists' Meeting held in Brussels, Belgium, 22-26 January 1979.

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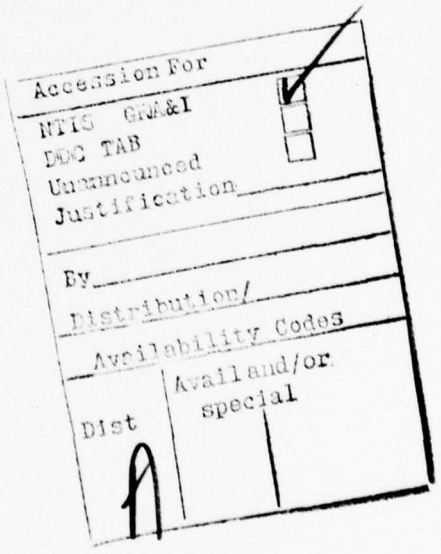
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PREFACE

On 26 January 1979 the Aerospace Medical Panel of the NATO Advisory Group for Aerospace Research and Development met at Brussels, Belgium. The title of this conference was "Recent Advances in Aeronautical and Space Medicine". This Report documents the proceedings of this conference and contains the five presented papers and a summary of the discussion following each paper. It also includes a Technical Evaluation.

This meeting was intended to update the members of the Aerospace Medical Panel and their selected guests in three topics of special interest: (1) selection and life support of aircrew and spacecrew (including European Payload Specialists of the Space Shuttle); (2) physiological factors in space operations; (3) medical and physiological problems faced during the development and operation of commercial supersonic vehicles.

The three days prior to this Session were devoted to the subject "Maintenance of Air Operations While Under Attack with Chemical Agents". The Report of these Sessions will be presented elsewhere.

Raymond H.Murray, MD
Session Organizer

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TECHNICAL EVALUATION REPORT
by
Raymond H. Murray, M.D.

This Report contains the proceedings of the fourth and final day, 26 January 1979, of a four day conference of the Aerospace Medical Panel of NATO's Advisory Group for Aerospace Research and Development held at Brussels, Belgium. The first three days of the meeting (Session A) were concerned with the "Maintenance of Air Operations While Under Attack With Chemical Agents". The proceedings of this meeting will be presented elsewhere. Session B was entitled "Recent Advances in Aeronautical and Space Medicine". This Report contains five papers presented in this Session and the attendant discussion.

The Program Committee designed this Session to present to the Aerospace Medical Panel members and selected guests the recent advances in three important fields: 1) selection, special training and life support of aircrew and spacecrew, including European Payload Specialists for the Space Shuttle; 2) physiological factors in space operations; 3) medical and physiological problems faced during the development and operation of the first commercial supersonic vehicle, the Concorde.

The first paper by Gén.-Maj. Méd. Evrard, reviewed in depth the medical criteria used for selecting military aircrew. In addition to a comprehensive discussion of the customary subjects in this field, he presented new material relating to the implications of the use of female personnel.

Group Captain Ernsting presented next the basic science concepts and clinical operational requirements that underlie the development of advanced oxygen systems for future high performance combat vehicles and proposed design criteria for such a system.

The European experience with the selection and training of Space Shuttle Payload Specialists was described by Doctors Klein and Hordinsky in the following paper, which also clarified the evolving role of Payload Specialists.

Doctors Pool, Rambaut and Homick reviewed the environmental stresses of space flight, the experience of NASA in earlier space programs and the physiological problems expected during the forthcoming Space Shuttle operation. They also discussed health care systems that have been developed to promote a safe and comfortable environment in which to work and rest in space.

Finally, Médecin Général Inspecteur Raboutet presented 10 years of physiological and medical experience with the supersonic transport, Concorde. He emphasized the importance of a close working relationship among physicians, chemists and engineers in solving potentially serious problems such as noise, pollution, ozone layer disruption, ionizing radiation, etc.

A review of the topics presented at meetings of this Panel over the past 7 years shows the priority previous Program Committees gave to the subject of selection of aircrew and life support systems. If one lumps together this and associated topics, they account for about 60% of all the topics held at these Sessions. This is as it should be, because of the obvious interest and importance of these matters to every NATO country. The medical and physiological effects of supersonic commercial aviation have never been discussed here before. Because of the importance of the commercial and military use of supersonic vehicles, it would seem essential that this subject be discussed often at these sessions in the future. The physiological and biochemical effects of space flight and their attendant health and performance implications is another subject that deserves greater emphasis. Three years ago this subject was discussed at your meeting in Athens and one of the papers today discusses this topic in some depth. But, this hardly seems sufficient for a subject so poorly understood by most of us and so important for the future of Aerospace Medicine. I need hardly remind you of the word "space" in the title of this panel.

Two other subjects would seem to warrant special consideration for future discussions by this Panel: the maintenance of the general health of airforce personnel; and, the study of combined environmental stresses.

While the subject of prospective medicine was presented at your London meeting 18 months ago, this is a most timely subject for a group of physicians charged with promoting the health and well being of large groups of young men and women, and some not so young. I would suggest that advances in this area are worthy of re-presentation from time to time. I'm talking particularly about the fruitful new demonstration programs involving the identification of risk factors for important chronic illnesses, such as coronary artery disease, and the potential benefits of intervention programs, which are being mounted in many of the countries represented here.

The subject of combined environmental stresses has been discussed here twice over the past seven years but only a limited amount of data was presented. Research in this field is very complex and extremely difficult to carry out. But, it must be a rare occurrence indeed when a pilot is exposed to a single, pure stress. Dr. Michael McCally and I wrote the chapter dealing with this subject in the Bioastronautics Data Book seven years ago. In our review of this subject we identified seven classes of environmental factors, seven host factors and four so-called reciprocative factors. Beyond the obvious

complexity of testing the hundreds of simple interactions, there are many hundreds of more complicated multiple interactions. And, the problem is further confounded by variables having to do with the order of occurrence of the stresses, their durations, severity and types of interaction - do they interact by simple addition of physiological effects, or perhaps synergistically, or antagonistically? There are added difficulties because of unstandardized stresses, varying criteria of tolerance and limited simulation capabilities.

But it has always seemed to me that an effective approach could be made if three resources were made available: (1) A large group of capable environmental physiologists and aerospace medicine clinicians who are interested and committed to working together for a long period of time on such a venture, and that suitable laboratory resources could be made available to support this research. (2) The group must have available for its use a large computer facility with systems analysis capability, because simulation modelling will be required to make meaningful progress. (3) An international organization that is interested in this field and would sponsor and promote such an endeavor. Of course, I have this organization in mind as this resource. I know of no other that can marshall the required resources and exert the necessary leadership.

Such a huge and complex undertaking can never actually be completed, but I'm convinced that very significant advances can be made that would be scientifically important and clinically useful. I should like to point out that such cooperative ventures in research and development are clearly spelled out in the mission of AGARD.

PROBLEMES RELATIFS AUX CRITERES MEDICAUX DE SELECTION DU PERSONNEL NAVIGANT MILITAIRE

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Résumé

L'auteur examine les critères médicaux de sélection du Personnel navigant militaire dans cinq domaines particuliers :

a. les critères visuels, auditifs et vestibulaires;
b. les critères de sélection psychologique ou psychiatrique;
c. le problème de critères spéciaux éventuels pour la détermination précoce ou immédiate de la spécialisation du pilote opérationnel;
d. le problème d'une élévation éventuelle des normes pour les aviateurs destinés à piloter les avions de combat de la nouvelle génération;
e. le problème du personnel navigant féminin.

L'auteur préconise une normalisation des critères visuels et auditifs.
Il recommande des nouvelles recherches sur les autres points considérés, afin de réduire le taux des éliminations au cours de l'entraînement à l'Ecole de pilotage.

GENERALITES

Les problèmes relatifs aux critères médicaux appliqués à la sélection du Personnel navigant militaire sont si nombreux, si complexes et si vastes qu'il serait présomptueux de vouloir couvrir l'étendue de la question dans les limites de temps dévolues à cet exposé.

Aussi, je me dois de préciser d'emblée les frontières que j'ai fixées à l'étude du sujet qui m'a été confié.

1. Depuis la création de l'Alliance Atlantique, parmi les problèmes majeurs auxquels les Forces aériennes de l'OTAN sont confrontées, l'un a toujours revêtu un aspect véritablement crucial : celui du recrutement du personnel navigant et, par conséquent, celui de la sélection des candidats aviateurs. En matière de critères médicaux, le mot "sélection" semblerait ne concerner que les critères appliqués à l'examen d'admission, à l'exclusion de ceux applicables aux examens périodiques de revision d'aptitude. Qu'il me soit permis de souligner, dès maintenant, que cette sélection du personnel navigant, selon moi, n'est pas un acte unique, initial, posé avant d'accorder ou d'interdire l'accès de l'apprentissage du vol et, par conséquent, d'une carrière dans le Personnel navigant. C'est plutôt un processus continu. Il commence par l'examen médical initial de sélection. Il se poursuit ensuite pendant toute la période de l'écolage en vol et même pendant la période qui lui fait suite immédiatement : celle de la spécialisation aux divers types d'avions ou d'hélicoptères et aux divers types de missions à effectuer. Mais, il va de soi que l'examen médical de sélection présente une importance capitale, ne fut-ce que sous l'angle purement financier. Barrer d'emblée le chemin à un candidat dont les chances de devenir pilote sont nulles ou précaires ou dont le déroulement d'une carrière navigante normale sera très vraisemblablement compromis en raison de l'évolution inéluctable de certaines déficiences, constitue une économie de temps, de moniteurs, d'avions, d'équipements et par conséquent d'argent. L'estimation la plus récente du coût de la formation opérationnelle d'un pilote de chasse qu'il m'a été permis de trouver dans un document AGARD est celle fournie par P. BLANC (1) dans l'AGARD report n° 666, publié en juin 1978 : selon cet auteur, la formation d'un pilote de chasse opérationnel français est estimée à 15 millions de francs français (100 millions de francs belges ou 3,4 millions de dollars ou 1,750 millions de livres sterling); la formation d'un pilote de Mirage 1 coûte le double, soit 30 millions de francs français (6,8 millions de dollars, 200 millions de francs belges ou 3,500 millions de livres sterling).
   C'est à la sélection clinique initiale que je me limiterai. Mais il reste bien entendu que les critères médicaux applicables à cette sélection clinique initiale doivent également s'appliquer pendant toute la durée de l'apprentissage du vol, soit pendant une période que l'on peut estimer grosso modo à 18 mois. Me référant aux catégories d'examens médicaux de l'USAF, il s'agit donc des critères de la "Flying Class I". Dans un but de simplification, je me limiterai à la seule fonction de pilote d'avion ou d'hélicoptère puisque c'est pour elle que se posent la plupart des problèmes importants.

2. Une autre considération doit également être émise, afin de faire la part des vrais problèmes et des faux problèmes. En face des difficultés du recrutement, il est bien connu - et on ne doit pas avoir peur de le dire ouvertement - que les autorités militaires ont toujours eu tendance à essayer d'obtenir des autorités médicales l'abaissement de certaines normes ou de certains critères contenus dans les règlementations

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médicales. Au cours des 25 dernières années, si l'on juge par le peu de modifications survenues dans les textes des règlements, on peut dire que d'une manière générale, les diverses réglementations d'expertise médicale d'aptitude ont pu opposer à ce genre de tendance une sorte de force d'inertie. Depuis la création de l'Alliance Atlantique, l'essentiel des réglementations concernant la sélection initiale est demeuré pratiquement identique. L'introduction de nouvelles méthodes ou de nouvelles techniques d'examen n'est consacrée par voie officielle que suivant un rythme d'une extrême lenteur, si on le compare à celui de l'adoption de nouveaux équipements de vol ou de l'adaptation de l'homme aux nouvelles performances de l'avion. Certains y verront l'oeuvre d'une tradition qui mériterait parfois d'être secouée. D'autres y trouveront une preuve de sagesse, celle qui impose l'apport de travaux scientifiques sérieux et de bases statistiques probantes, que seul le temps permet de fournir, avant qu'il soit question d'introduire des modifications importantes dans les publications officielles réglementaires relatives aux critères médicaux d'aptitude au vol.

Quoi qu'il en soit, il semble qu'une certaine révision de valeurs consacrées par la tradition et qu'un certain contrôle de données divergentes rencontrées dans les réglementations des diverses Forces aériennes de l'OTAN soient parfois opportuns ou nécessaires, ne fut-ce que pour stimuler de nouvelles recherches, principal outil pour le perfectionnement de nos méthodes de sélection.

Selon les recommandations et directives que j'ai reçues du Président du Comité des programmes, l'Air Commodore COOKE, les points suivants ont été retenus pour une brève revue des principaux critères d'aptitude médicale, en vue de souligner surtout les lacunes, les incertitudes, les imperfections qu'on y relève ou même les controverses qui les entourent. Il s'agit donc de points qui sollicitent ou exigent de nouvelles investigations des chercheurs.

a. les critères visuels, auditifs et vestibulaires, (ces derniers étant surtout centrés sur la sensibilité au mal de l'air);
b. les critères de sélection psychologique ou psychiatrique;
c. le problème de critères spéciaux pour la détermination précoce ou immédiate, dès le premier examen médical de sélection, de la spécialisation du pilote opérationnel (pilote d'avion de chasse, pilote d'avion de transport, pilote d'hélicoptère, etc...);
d. le problème d'une élévation éventuelle des normes pour les aviateurs destinés à piloter les avions de combat de la nouvelle génération, dits "avions à haute performance" (F16, F15, etc...);
e. les problèmes relatifs au personnel navigant féminin.

3. Une autre considération préalable, d'un tout autre ordre, mérite aussi d'être soulignée. Afin que l'autorité militaire, en considérant la somme des échecs survenus dans l'apprentissage du pilotage, n'attribue pas aux experts médicaux des échecs qui ne sont pas imputables à la sélection médicale, il importe de préciser, sur le plan technique, l'objectif de la sélection médicale initiale.

Selon moi, la sélection médicale initiale doit mettre en évidence chez le candidat aviateur deux catégories de qualités :

a. des qualités professionnelles;
b. des qualités de résistance à l'égard de multiples agents stressants intervenant au cours du vol et pouvant compromettre la sécurité de ce dernier.

(1) <u>des qualités professionnelles</u>

Elles sont de deux sortes. Les unes, portant principalement sur le domaine neuro-moteur, interviennent uniquement dans la <u>technique du pilotage</u>. Les autres intéressent plus directement la <u>sécurité du vol</u> : ce sont principalement celles intéressant la vision, l'audition, les fonctions mentales et caractérielles, la fonction cardio-vasculaire, la fonction respiratoire et à un moindre degré les autres fonctions corporelles. La plus grande partie des critères médicaux de sélection vise à la détection de ces qualités.

(2) <u>des qualités de résistance</u> à de multiples agents intervenant soit au cours du vol, soit dans les conditions de survie, de saut en parachute, ou tout simplement dans les états de fatigue résultant de la nature et de la fréquence des missions aériennes. A cet égard, il paraît logique de réclamer, dès le début de la carrière, un certain capital de stabilité psychique et d'endurance physique, susceptible d'être éventuellement fortifié par l'entraînement, pendant le séjour en école et en unité.
Tel est l'axe directeur qui doit guider notre travail d'évaluation sur la valeur des dispositions réglementaires qui vont être discutées.

Nous nous proposons maintenant d'examiner les 5 points mentionnés plus haut, soit qu'ils méritent considération pour des recherches, soit qu'ils inspirent réflexion, en vue d'une refonte éventuelle de certaines de nos conceptions.

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I. CRITERES VISUELS, AUDITIFS ET VESTIBULAIRES

A. CRITERES VISUELS

L'examen de la vision constitue l'un des points les plus importants de la sélection médicale des aviateurs.

Si l'on observe la répartition des causes d'élimination par systèmes ou par fonctions, on constate que celles liées à la fonction visuelle l'emportent de très loin. Actuellement, comme dans le passé, elles interviennent à la Force aérienne belge dans la moitié du nombre des candidats élèves-pilotes éliminés.

1. Acuité visuelle

Une acuité visuelle excellente est particulièrement utile au pilote de combat (chasse, reconnaissance, bombardement). Toutefois, l'acuité visuelle, mesurée à la distance de 6 mètres (20 pieds), avant l'instillation d'un cycloplégique, ne fait pas l'objet d'exigences identiques dans toutes les Forces aériennes, pour l'examen initial de sélection.
On trouvera dans le tableau 1 les normes réglementaires appliquées dans 9 Aviations de l'OTAN (2).

Tableau I.

NORMES REGLEMENTAIRES D'ACUITE VISUELLE DANS 9 AVIATIONS MILITAIRES POUR LES CANDIDATS PILOTES

Forces aériennes	Vision sans verres correcteurs		Obligation de corriger au moyen de verres	
Belgique	10/10	10/10	-	-
USAF	10/10	10/10	-	-
US Navy	10/10	10/10	-	-
US Army	10/10	10/10	-	-
Norvège	10/10	10/10	-	-
Canada	6/ 6	6/ 9	-	-
France	9/10	9/10	10/10	10/10
RAF (Grande-Bretagne)	6/ 9	6/ 9	10/10	10/10
République Fédérale d'Allemagne	5/10	5/10	10/10	10/10

On constate que pour les candidats pilotes toutes catégories, sur 9 réglementations étudiées :

cinq exigent l'unité pour chaque oeil pris isolément, sans correction par des verres;

une exige l'unité à un oeil et 6/9 à l'autre oeil sans correction;

une exige 9/10 à chaque oeil sans correction, à condition que la vision puisse être corrigée à l'unité pour chaque oeil, au moyen de verres;

une réglementation n'exige que 6/9 à chaque oeil à condition que la vision puisse être corrigée à l'unité, pour chaque oeil au moyen de verres;

une réglementation n'exige que 5/10 à chaque oeil, à condition que la vision puisse être corrigée à l'unité pour chaque oeil au moyen de verres.

On peut conclure que toutes les réglementations imposent l'unité à chaque oeil, les unes sans verres correcteurs, les autres avec l'aide de verres correcteurs. Le problème qui se pose peut se formuler comme suit : faut-il exiger à l'examen initial une acuité visuelle égale à l'unité, sans verres correcteurs? ou bien, quelles sont les conséquences, à court terme ou à long terme, des tolérances

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permettant de descendre à 9/10 (France), ou à 6/9 (RAF) ou à 5/10 (Luftwaffe)?
Le problème est d'importance si nous considérons le pourcentage élevé des éliminations résultant de l'exigence de l'unité aux 2 yeux sans verres correcteurs.
Certes, il est bien connu que les critères médicaux d'aptitude ne sont pas seulement liés à des problèmes de sécurité du vol ou encore à des problèmes de capacité d'apprentissage du pilotage ou de rendement de la mission aérienne.
Des problèmes, d'une nature extra-médicale, tels ceux du recrutement d'un nombre suffisant de candidats pour que l'offre puisse répondre à la demande, pèsent d'un certain poids, variable selon les circonstances et les pays, sur la sévérité de certains critères. C'est sûrement le cas pour les critères d'acuité visuelle, puisqu'ils sont responsables du taux d'élimination le plus élevé.
Si nous restons sur un plan strictement médical, en matière de tolérance, deux facteurs doivent être considérés :

a. les inconvénients du port de verres correcteurs pour les pilotes de combat;
b. la progression des défectuosités de la vision avec l'âge (principalement la myopie) quand ces défectuosités existent déjà à 20 ans.

Si l'élimination d'un pilote, pour insuffisance d'acuité visuelle, peut être admise, avec une résignation acceptable pour l'intéressé et le Commandement après l'âge de 40 ans, elle est un désastre pour l'aviateur qui en est la victime et un inconvénient sérieux pour le Commandement quand elle s'opère autour de la trentaine. Il est d'ailleurs à remarquer que la réglementation de la RAF présente à ce sujet la disposition suivante : quand l'expert estime que des lunettes de vol avec verres correcteurs seront nécessaires dans un certain avenir, la décision d'admission relève du Ministère de la Défense.
Il est évident que ces inconvénients et ces risques sont beaucoup moins grands si la tolérance admise est très faible, comme c'est le cas pour la réglementation française.
En ce qui concerne les tolérances jusqu'à 6/9, des conditions expérimentales intéressantes se sont produites dans la Force aérienne belge, à la suite de l'incorporation dans la Section belge de la RAF, pendant la guerre 1939-1945, de jeunes gens belges, admis dans le personnel navigant, avec un certain degré de myopie ou d'astigmatisme réduisant l'acuité visuelle jusqu'à 6/9 (3). Avec le recul, on peut dire que cette tolérance initiale a été une source continuelle de difficultés en raison de la progression inéluctable de la myopie, de la nécessité de pourvoir ces aviateurs de lunettes de vol avec des verres correcteurs et de prévoir des changements périodiques de verres et enfin, en raison de l'obligation de faire affecter ces aviateurs à des unités de transport ou à des Etats-Majors , après quelques années passées en unité de chasse. Pour une grande Force aérienne disposant de nombreux effectifs, ce genre de mutations ne crée pas de graves difficultés. Mais, dans une Force aérienne dont les effectifs en pilotes opérationnels sont de l'ordre de 500 pilotes et où les unités de chasse constituent la plus grande partie des unités navigantes, ces mutations prématurées et obligées, nécessitant une reconversion à des fonctions de pilote de transport, très souvent à l'encontre du désir des intéressés, suscitent des difficultés qui retentissent défavorablement sur le déroulement d'une carrière militaire normale, sur la motivation et le moral de ceux qui en sont l'objet.
Nous croyons donc que les tolérances consenties lors de l'examen initial dans le domaine de l'acuité visuelle relèvent, en ordre principal, de facteurs extra-mécaux...
Malgré l'aide considérable et irremplaçable des équipements de bord modernes, le pilote d'un avion de haute performance en mission de combat, surtout dans les missions à basse altitude et à grande vitesse, aura toujours besoin d'une vision lui fournissant, sur des objectifs situés à distance éloignée, des informations précises et nettes, dont la perception correcte et l'interprétation mentale rapide seront un élément important de sa supériorité sur l'adversaire et du rendement de sa mission.
Aussi, en ce qui concerne l'aviation de l'avenir, nous ne croyons pas qu'il existe actuellement des arguments nouveaux permettant de réduire le rôle de l'acuité visuelle à distance.
Nous pensons donc que l'idéal demande d'exiger, de tout candidat pilote militaire toutes catégories, une acuité visuelle égale à l'unité à chaque oeil, sans verres correcteurs, et cela malgré les déchets importants dont cette clause est le prix. Nous estimons qu'à tout prendre, cette façon de faire est la plus rationnelle pour les Forces aériennes qui ne disposent que d'effectifs assez limités et dont les unités ont des activités principalement axées sur les missions de chasse et d'appui des troupes au sol.
Toutefois, il va de soi que l'expérience obtenue dans les Forces aériennes à très grands effectifs et qui, grâce à la grande variété des missions qu'elles assument, peuvent se permettre de tolérer l'admission de candidats présentant déjà un certain degré de myopie à l'examen initial, devrait nécessairement être versée au dossier et être prise en considération, si un débat devait être rouvert sur cette question.

2. Lentilles de contact

La question du port des lentilles de contact est temporairement close, en ce qui concerne les dispositions réglementaires. L'utilisation des verres de contact est refusée dans toutes les réglementations, à l'examen d'admission. Il

s'agit d'une règle générale, ne souffrant pas d'exception, à notre connaissance. Ce n'est que lors des examens revisionnels que l'on trouve des dérogations sous ce rapport. Parmi les sept pays dont nous avons étudié les réglementations pour la rédaction de l'Agardographie 213 (2), deux seulement, la France et le Royaume-Uni, ont prévu dans leur règlement des dispositions qui autorisent le port de lentilles de contact, dans des conditions bien déterminées.
Dans l'Armée de l'Air française, ces conditions sont très strictes et très limitées. C'est uniquement pour les standards de vision n°4 et n°5 qu'il est prévu une possibilité d'utilisation de lentilles de contact, mais elle doit, pour chacun des cas, faire l'objet d'une autorisation individuelle après examen objectif de la tolérance. Les bénéficiaires de cette faveur ne sont pas des candidats pilotes toutes catégories, ni des élèves-pilotes, ni des pilotes de combat, ni des pilotes d'hélicoptère; les standards 4 et 5 s'adressent uniquement à des pilotes de transport, de bombardement conventionnel et de liaison bi-moteur, ou encore à des pilotes d'avion estafette ou des pilotes d'avion mono-moteur d'appui léger ou à des membres du Personnel Navigant de l'Aviation légère de l'Armée de Terre et de la Gendarmerie.
Dans la Royal Air Force, les aviateurs confirmés ne peuvent être autorisés à porter des verres de contact que sur avis favorable du médecin consultant en ophtalmologie. Le texte de la réglementation ne donne aucune précision sur les conditions qui entourent l'octroi d'une telle autorisation.

3. Vision des couleurs

Les anomalies de la vision des couleurs entraînent un pourcentage d'éliminations qui peut se chiffrer entre 7% et 10% des candidats. Ce pourcentage énorme a toujours obsédé les autorités militaires responsables du recrutement des aviateurs. C'est sans doute ce qui fait rebondir périodiquement le problème.
Depuis 50 ans, on n'a cessé de discuter sur l'importance pratique d'une vision parfaite des couleurs dans la conduite de l'avion. Le pilote doit lire correctement et rapidement les informations qui lui sont présentées sur le tableau de bord : certaines lui sont fournies avec l'aide d'indices colorés, précisément en vue de faciliter leur lecture et leur interprétation. La mise en service de nouveaux systèmes d'information utilisant des écrans cathodiques - ce qui semble devoir être une présentation qui sera de plus en plus employée dans les avions de la nouvelle génération - n'exclut pas l'emploi de codes colorés. Bien au contraire. La couleur semble même devoir être beaucoup plus utilisé dans ces nouveaux systèmes.
D'autre part, malgré l'abondance des informations auditives, le pilote aura toujours à interpréter le message du sol qui lui parvient sous forme de feux colorés codés. Il doit aussi pouvoir lire sans erreur des cartes colorées. Ces exemples, parmi bien d'autres, nous paraissent suffisants pour continuer à exiger la normalité dans la perception des couleurs.
La cause nous semble donc entendue sous ce rapport, même avec les nouveaux concepts de présentation du poste de pilotage.
Ceci ne signifie pas qu'une étude sur l'importance pratique d'une vision parfaite des couleurs en aviation et les conséquences de certaines anomalies ne serait plus justifiée.
Périodiquement, les partisans d'un relâchement dans la rigueur des critères de sélection font valoir que beaucoup de couleurs ne se trouvent que sur des indicateurs de position, que tout risque de confusion de couleur est éliminé et que d'autres moyens d'identification des couleurs au moyen de lettres, de dessins, de formes géométriques sont souvent disponibles. Ces considérations n'ont jamais été convaincante. . Il semble que les futurs systèmes de cockpit devront encore compter pendant longtemps sur l'usage d'un code coloré. Toute interprétation douteuse ou erronée étant une cause potentielle d'accident, il n'y a pas lieu, à court terme et même moyen terme, de revenir sur cette question. C'est un autre aspect de ce problème qui me paraît être beaucoup plus pratique. A l'époque où au sein de l'Alliance Atlantique, des jeunes gens reçoivent ou peuvent être amenés à recevoir l'entraînement au pilotage en dehors de leur pays d'origine, dans des écoles dépendant d'une Force aérienne alliée, il serait hautement souhaitable que des experts arrivent enfin à s'accorder pour proposer et fixer, une fois pour toutes, une méthode normalisée d'appréciation des anomalies des couleurs incompatibles avec la pratique de l'aviation militaire et la sécurité aérienne, dans les Forces aériennes de l'OTAN.

4. Hypermétropie - Hétérophories

Dans ce domaine de l'unification, le même problème existe concernant d'autres éléments de l'examen visuel de sélection. Je serai bref à leur sujet et ne discuterai pas la valeur de l'importance qu'on leur attribue. Mais ne pourrait-on fixer, dans les Forces aériennes de l'OTAN une valeur numérique commune pour le degré d'hypermétropie entraînant l'élimination? Ne pourrait-on faire de même pour la question des hétérophories? Il paraît aberrant qu'un candidat puisse être acceptable dans certaines Forces aériennes de l'Alliance et être refusé dans d'autres pour de tels éléments intervenant dans l'évaluation de la fonction visuelle.

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Le tableau comparatif n° 2 nous paraît suffisamment suggestif à cet égard.

Tableau 2.

MAXIMUM ADMISSIBLE POUR L'HYPERMETROPIE ET LES HETEROPHORIES (en dioptries)

POUR LES CANDIDATS PILOTES

Forces aériennes	Valeurs limites d'			
	Hypermétropie	Esophorie	Exophorie	Hypo- ou Hyperphorie
Belgique	2.25	8	6	1
Canada	2.50	6	6	1
République Fédérale d'Allemagne	2.00	10	5	1.5
France	2.00	6	6	1
Grande-Bretagne	2.25	6	8	1
Norvège	1.75	10	5	1.5
USAF	1.75	10	5	1.5
US Navy	2.50	10	10	1
US Army	1.75	10	5	1.5

En présence d'une variabilité aussi marquée, on est en droit de se demander s'il ne conviendrait pas de revoir toute cette question, sans aucun préjugé.
Encore,faut ajouter qu'en matière d'hétérophorie, si les limites citées au tableau 2 sont dépassées, il n'y aura pas d'élimination du candidat pilote, selon les réglementations française, britannique et allemande, si un examen orthoptique décèle une amplitude de fusion suffisante et si l'épreuve au caisson à dépression, à l'altitude de 3,500 mètres, pendant 20 minutes, n'entraine aucune diplopie objective. Aussi, la signification pratique des valeurs numériques assignées aux limites d'hétérophories dans les diverses réglementations paraît, pour le moins, sujette à caution aussi longtemps que ces discordances n'auront pas disparu.

5. Perception des distances et du relief

Sa détermination n'est pas prévue dans les réglementations britannique et belge. Les autres réglementations utilisent les mêmes méthodes et le critère de normalité est bien fixé dans les deux techniques utilisées, à savoir les stéréogrammes du type Verhoeff et l'appareil de Howard-Dolman.
Le véritable problème qui se pose à propos des tests proposés pour mesurer la capacité de perception des distances et du relief chez les candidats porte, non pas sur la nécessité de posséder une perception correcte en ce domaine, - ce qui va de soi -, mais sur la signification réelle de ces épreuves dans la sélection des aviateurs. La question est de savoir s'il est raisonnable et justifié d'éliminer des candidats qui ne réussisent pas ces épreuves, alors que l'appréciation des distances et du relief met en jeu, au décollage, en vol et à l'atterrissage, des facteurs importants de caractère monoculaire, qui n'interviennent pas dans ces épreuves utilisées pour la sélection.

6. Résistance à l'éblouissement

Sa mesure est obligatoirement pratiquée en France, à l'examen d'admission pour tous les candidats pilotes. Elle se mesure par le test de Baillart. Elle doit ensuite être réalisée tous les 5 ans en expertise révisionnelle pour tous les pilotes. Si le test de résistance à l'éblouissement est anormal, mais si le bilan de la fonction maculaire ne révèle aucune anomalie, une orientation vers le transport sera proposée.
Cette étude est également réalisée en Allemagne, à l'examen d'admission.
Elle n'est pas effectuée dans les Forces américaines, ni à la RAF, ni dans la Force aérienne belge, ni dans la Force aérienne canadienne, ni dans la Force aérienne norvégienne.

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7. Seuil morphoscopique nocturne

Il est mesuré, dans l'Armée de l'Air française, lors de l'examen d'admission, à l'aide du scoptomètre de Beyne.
Dans l'Armée de l'Air allemande, cette épreuve n'est pas pratiquée systématiquement à l'examen d'admission. On l'effectue lorsque les antécédents familiaux ou personnels, l'état des milieux réfringents ou les modifications du fond de l'oeil font craindre une déficience de l'adaptation à l'obscurité ou lorsque celle-ci se manifeste à l'occasion du test de résistance rétinienne à l'éblouissement, ou du comportement dans l'obscurité.
A l'USAF et l'US Navy, le test n'est pas pratiqué systématiquement, mais seulement dans des circonstances semblables à celles prévues dans la réglementation allemande.
Les autres réglementations stipulent que la vision de l'aviateur doit être normale dans l'obscurité, mais n'énoncent pas une technique déterminée, ni des prescriptions particulières.

8. En conclusion :

Les critères relatifs à la fonction visuelle ont toujours constitué la cause la plus importante des éliminations chez les candidats aviateurs militaires. La réduction des capacités visuelles par l'âge est une source de difficultés en cours de carrière, si des tolérances trop larges sont admises lors de l'examen initial, en matière d'anomalies de réfraction.
Malgré la précision des techniques d'examen en ophtalmologie, on constate des divergences importantes dans les valeurs limites prévues pour l'admission en ce qui concerne les normes de vision. Il semble donc qu'un effort de recherches, préparatoire à une unification des concepts sur le plan médical, à l'exclusion de l'intervention des concepts extra-médicaux, qui viennent parfois s'ajouter pour infléchir et assouplir les désiderata médicaux, soit une recommandations légitime et justifiée au moment où une nouvelle génération d'avions de combat commence à équiper les Forces aériennes de l'OTAN.
Quant aux tests dont l'emploi n'est obligatoire à l'admission que dans un ou deux pays, le test de résistance à l'éblouissement par exemple, il est souhaitable que l'apport positif de ces tests à la sécurité aérienne puisse être établi et démontré, en indiquant le prix qu'ils exigent sous forme de pourcentage d'élimination de candidats, afin que la généralisation de leur emploi, si elle est proposée, puisse être recommandée sur des bases scientifiques convaincantes et irréfutables aux autres Forces aériennes de l'Alliance.

B. CRITERES AUDITIFS

Comme il n'existe pas de grandes divergences dans les règles relatives à la pathologie oto-rhino-laryngologique, nous nous limiterons au problème de l'acuité auditive où règne un certain degré de discordance entre les diverses prescriptions réglementaires nationales.

Toutes les réglementations demandent qu'un audiogramme tonal en conduction aériennes soit pratiqué dans le silence, pour tous les candidats.

Dans certains cas, une exploration plus complète peut être nécessaire. Elle fait appel aux différents tests d'audiométrie tonale et vocale.

Comme pour l'acuité visuelle, des différences importantes existent au sujet du déficit maximum admissible pour chaque fréquence.

Le tableau 3 est un tableau comparatif des déficits auditifs admissibles pour les candidats élèves pilotes dans 9 réglementations (2).

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Tableau 3.

TABLEAU COMPARATIF DES DEFICITS AUDITIFS ADMISSIBLES POUR CANDIDATS PILOTES

Fréquences en hertz	Perte admise en décibels pour chaque oreille (Standard 151.1951)								
	France	Belgique	Grande Bret.	Canada	Allemagne	US Army	US Navy	USAF	Norvège
250	20	15	20	-	20	-	-	-	-
500	20	15	20	20	20	15	10	15	15
1000	20	15	20	20	20	15	15	15	15
2000	20	15	20	20	20	15	15	15	15
3000	30		20	20		-	35		
		total de 160 db pour les 2 fréquences les			total de 210 db pour les 2 oreilles			total de 210 db pour les 2 oreilles	total de 210 db pour les 2 oreilles
4000		plus déficitaires aux 2 oreilles	20	-		40	50		
8000			-	-		-	-		

Le tableau 3 montre que :

1. cinq des 9 réglementations ne font aucun usage de la fréquence 250 hertz;
2. pour la fréquence de 500 hertz, une réglementation autorise un déficit de 10 db, quatre réglementations admettent un déficit maximum de 15 db et quatre autres un déficit maximum de 20 db;
3. pour la fréquence de 1.000 hertz, cinq réglementations permettent un déficit maximum de 15 db et quatre réglementations un déficit maximum de 20 db;
4. pour la fréquence de 2.000 hertz, cinq réglementations permettent un déficit maximum de 15 db et quatre réglementations un déficit maximum de 20 db;
5. à partir de 3.000 hertz, les discordances sont telles qu'une comparaison n'est plus utile.

En ce qui concerne les exigences relatives à l'audiogramme tonal, imposé dans toutes les réglementations, on relève donc des différences suffisamment importantes pour donner matière à des études plus approfondies qui devraient déboucher, elles aussi, sur une meilleure concordance, à défaut d'une unification parfaite des réglementations en ce domaine.

C. FONCTION VESTIBULAIRE ET MAL DE L'AIR

Le mal de l'air atteint un nombre relativement important d'élèves-pilotes au cours de l'apprentissage du pilotage.

Dobie (4), à ce propos, cite dans l'Agardographe 177 les chiffres récents suivants, basés sur les rapports des moniteurs dans les écoles de pilotage de la RAF. Sur les 577 élèves-pilotes sur lesquels l'enquête a porté, 24,1% ont souffert d'une forme légère de mal de l'air durant l'entraînement au pilotage. Cette forme légère a contrarié l'entraînement mais n'a pas conduit à un retard notable dans la progression de l'instruction en vol. 14,6% des élèves ont souffert d'une forme de mal de l'air suffisamment grave pour interférer avec la progression de l'entraînement et déterminer, en conséquence, l'élimination de certains d'entre eux.

Ainsi donc, selon cette statistique s'appliquant à un groupe soumis aux méthodes actuelles d'entraînement, 38,7% des élèves-pilotes ont souffert de mal de l'air à l'une ou l'autre période de leur entraînement, le plus souvent la période initiale. La perte de temps utile a été particulièrement importante chez 15% des élèves.

Les pertes considérables de temps et d'argent dans l'application des programmes d'entraînement, et la perte d'un lot d'élèves-pilotes se situant entre 1 à 8% méritent qu'une attention particulière soit portée au problème.

Il est facile de résumer le contenu des réglementations sur ce point, car il est bref et avare de détails... Chez le candidat pilote et chez l'élève-pilote, la sensibilité excessive au mal de l'air et au mal des transports, basée sur des antécédents

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acceptables et vérifiables, doit faire soupçonner une hyper-excitabilité vestibulaire ou une lésion vestibulaire. Le mal de l'air ne peut entrainer une décision d'inaptitude que si son caractère non améliorable paraît démontré, après examen éventuel par le médecin psychologue. Le mal de l'air survenant chez des personnalités psychopathiques entraine l'inaptitude. Dans la réglementation de l'USAF, la décision finale relève du Surgeon Air Training Command ou du Surgeon Air Force Academy.

Le texte de la réglementation française relatif aux expertises révisionnelles me paraît particulièrement clair - je le cite :

"Le mal de l'air disparaît dans la plupart des cas après une certaine période d'accou-
"tumance. Il ne peut devenir une cause d'inaptitude que si son caractère non amélio-
"rable, lié soit à des troubles de l'adaptation, soit à des troubles labyrinthiques,
"paraît démontré. L'avis des experts de psychologie et d'oto-rhino-laryngologie de-
"vient alors indispensable pour prendre une décision".

En ce qui concerne les tests à mettre en oeuvre et l'interprétation de leurs résultats, les réglementations sont extrêmement discrètes dans leur recommandation. De la littérature sur le sujet, on peut conclure que l'anxiété est considérée comme un facteur très important, sinon le plus important, dans la pathogénie du mal de l'air, surtout dans les formes graves. Nous traiterons cet aspect dans la section suivante de ce rapport, consacrée à la sélection psychologique et à sa complexité.

Sur le plan vestibulaire, l'examen clinique consiste à rechercher si les réponses labyrinthiques sont normales et harmonieuses aux stimulations cliniques. Celles-ci sont réalisées par des épreuves rotatoires, par des épreuves thermiques froides et chaudes et par la recherche en électronystagmographie d'un nystagmus spontané latent.

Malgré l'exécution de ces épreuves, les retards sérieux dans la progression de l'entrainement et les éliminations en école de pilotage pour le motif de mal de l'air montrent les difficultés, voire l'impossibilité pour les spécialistes ORL et les psychologues de prévoir avec certitude, par la conjonction de leurs moyens, la survenue et l'importance d'une cinétose. Le problème n'est pas neuf. Il a été posé déjà au temps de la première guerre mondiale. A une époque plus proche de nous, en 1951, Grandpierre, Labarthe et Lemaire (5) proposaient d'utiliser des épreuves globales qui permettraient l'investigation de l'équilibration dans son ensemble avec sa symptomatologie neuro-végétative, puis de soumettre les résultats au critère succès-échec en école de pilotage pour déterminer leur valeur prédictive. Lors du premier symposium du Panel aéro-médical de l'AGARD en décembre 1954 à Paris, j'avais rapporté les résultats d'une expérimentation assez prometteuse que j'avais immédiatement menée dans ce sens sur 1.200 élèves-pilotes entre 1951 et 1954 (3). Il s'agissait d'une épreuve rotatoire assez violente, suivie d'une mesure du temps nécessaire pour reprendre la position verticale stable dans l'épreuve de Romberg sensibilisée. Les sujets considérés comme hyperexcitables (temps supérieur à 60secondes)représentaient 8,75% d'un lot de 1.200 candidats pilotes : 80% de ces sujets hyperexcitables (soit 7% de l'ensemble des candidats) étaient éliminés au cours de l'Ecole de pilotage élémentaire, dont 20% pour mal de l'air (1,75% de l'ensemble des candidats). Les efforts poursuivis dans cette même direction de 1960 à 1978, en considérant le comportement du sujet, y compris dans ses réactions neuro-végétatives, quand il est sous l'influence de stimuli provoquant des réactions vestibulaires de Coriolis,ont fourni des résultats extrêmement encourageants chez des investigateurs américains (6), canadiens (7), et néerlandais (8).

En effet, les évaluations, résultant de ces tests de désorientation, établissent qu'ils possèdent une valeur prédictive significative sous l'angle succès-échec à l'école de pilotage, surtout quant à l'apparition du mal de l'air au cours de l'entrainement en vol.

Récemment, M. Lentz et F.E. Guedry (9) ont confirmé ces conclusions. Ils rapportent les résultats fournis par trois tests de désorientation vestibulaire constituant une batterie destinée essentiellement à l'évaluation de la fonction vestibulaire. Ces tests sont le Brief Vestibular Desorientation Test (BVDT), le Tilted-Axis Rotation Test (TART), et le Visual-Vestibular Interaction Test (VVIT). Comme l'exécution de ces tests s'accompagne de nausées et de malaises chez certains individus, ces auteurs se sont efforcés d'établir des techniques d'évaluation de ces malaises durant l'exécution des tests en vue d'établir la sensibilité au mal de l'air. Chaque sujet fait l'objet d'une estimation basée sur les constatations de 3 observateurs pendant et après l'épreuve et sur les réponses données par le sujet lui-même à un questionnaire centré sur ses malaises et sensations. L'étude de Lentz et Guedry est une comparaison rétrospective des résultats de ces 3 tests sur un groupe de 47 officiers ayant souffert de nombreux épisodes de mal de l'air pendant l'entrainement en vol et sur un groupe de 127 officiers et marins pris comme groupe témoin. Le BVDT, qui est le plus simple en matière d'équipement, met en jeu des accélérations de Coriolis au cours de rotations sur un fauteuil tournant grâce à des mouvements de tête. Il induit une réaction immédiate de peur,ce qui est un facteur intéressant à retenir. Cette réaction est parfois accompagnée de nausées et de vômissements. Dans les deux autres tests, réclamant un équipement beaucoup plus complexe, la réaction de peur est plus lente à s'établir. L'étude statistique des résultats confirme que le BVDT, déjà validé comme prédicteur de succès ou d'échec à l'entrainement en 1966 (10) possède également un coëfficient de corrélation significatif avec la sensibilité au mal de l'air.

Quant aux deux autres tests, l'étude statistique montre leur utilité dans la poursuite de cette même prédiction, mais dans une moindre mesure que le BVDT. Une cote résultant de l'addition des scores des 3 tests fournit une séparation plus nette que la

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cote obtenue par une seule mesure entre le groupe des sujets sensibles au mal de l'air et le groupe témoin.

Cette étude établit donc d'une manière convaincante qu'un test de désorientation mettant en jeu des accélérations de Coriolis et ne nécessitant pas un équipement très onéreux et complexe, est capable de fournir des indications pronostiques d'un haut degré de prédiction sur le succès ou l'insuccès à l'Ecole de Pilotage élémentaire et aussi sur la sensibilité au mal de l'air.

Evidemment, même si ces résultats se renforcent encore par un complément de confirmation provenant de recherches similaires effectuées dans d'autres Forces aériennes, il serait vain d'espérer l'éradication totale du mal de l'air chez les élèves-pilotes pendant leur apprentissage. Le mal de l'air n'est pas seulement tributaire de l'excitabilité de l'appareil vestibulaire. Il l'est aussi de l'inadaptation à la situation aéronautique vécue par l'élève-pilote et nous savons que l'interprétation de celle-ci se modifie parfois d'une manière soudaine et inattendue. Notre critère de validité des tests effectués à l'examen de sélection devra donc se limiter à une courte période : celle de l'entrainement élémentaire au vol.

Même avec une telle limitation de nos objectifs, on aurait déjà réalisé un gain considérable, si l'on pouvait prédire avec certitude ceux des candidats qui échoueront inéluctablement dans la première phase de l'entrainement pour hyperexcitabilité vestibulaire et qu'il est donc inutile d'accepter pour un essai, parce que leurs chances d'adaptation sont pratiquement nulles. L'économie qui en résulterait est suffisamment grande pour s'acharner sur cet objectif,si limité soit-il.

Les cas qui se produiraient encore au cours de l'entrainement en vol ou en unité seront, non pas synonymes d'une pauvre fiabilité de nos tests lors de l'examen initial, mais la confirmation que l'adaptabilité au milieu aéronautique est un facteur mouvant comme la vie et comme toute activité de l'esprit humain.

L'éviction, dès l'examen initial de sélection, des sujets hyperexcitables qui n'ont aucune chance d'arriver au terme de l'Ecole de Pilotage, quelque 18 mois plus tard, et la détection de ceux pour lesquels une trop grande patience, pendant l'entrainement, n'est pas rentable, s'ils vomissent d'une manière répétée après le 10ème vol à l'Ecole de Pilotage, (K.E. Money (19)), méritent que ces tests prennent place dans la batterie des examens de sélection. Ce qui importe surtout, c'est que des recherches soient poursuivies selon cet axe, dans l'espoir qu'elles puissent conduire à une sensibilité encore plus grande de leur pouvoir de discrimination tout en leur gardant leurs qualités essentielles de simplicité dans leur technique et d'économie dans l'équipement qu'elles exigent.

II. SELECTION NEUROLOGIQUE, PSYCHOLOGIQUE ET PSYCHIATRIQUE

A. SELECTION NEUROLOGIQUE

Toutes les réglementations séparent nettement ce qui relève de la neurologie et ce qui appartient au domaine de la psychopathologie et de la psychiatrie, bien qu'en pratique, l'examen neurologique et l'examen psychiatrique présentent parfois des aspects qu'il est difficile ou impossible de dissocier au cours de l'expertise médicale.

Le taux d'élimination du Personnel navigant en cours de carrière pour des motifs neurologiques est très faible. Ceci semble démontrer le caractère adéquat des réglementations appliquées lors de l'examen d'admission. L'examen électro-encéphalographique qui est maintenant pratiqué systématiquement à l'examen d'admission, contribue certainement à réduire les éliminations en cours d'entrainement ou en cours de carrière, en identifiant les sujets susceptibles de développer des incidents de nature épileptique.

L'interprétation des tracés EEG, pour ce qui concerne l'examen initial de sélection des aviateurs,a donné lieu à beaucoup de critiques, dues en grande partie aux difficultés rencontrées pour fixer la notion de normalité des tracés. Il en est résulté un taux, jugé abusif par beaucoup, des éliminations basées uniquement sur des dysrythmies, qui par simple mesure de sécurité furent estimées en dehors des limites du concept de normalité.

Tout récemment, E.M.R. Critchley (11) constatait que beaucoup de critiques adressées par le Professeur W.B. Matthews en 1964 sur les techniques d'électro-encéphalographie et les abus dans l'interprétations des tracés demeurent malheureusement vraies aujourd'hui.

Il semble cependant que, dans les Forces aériennes, si l'on juge d'après les plus récentes directives officielles émises pour l'interprétation des tracés, on soit maintenant arrivé à une conception, permettant de prémunir le spécialiste EEG contre des interprétations abusives.

La réglementation de l'USAF se borne à dire que "les anomalies électro-encéphalographiques chez des individus qui, pour le reste, sont apparemment en bonne santé, ne disqualifient pas nécessairement sauf en cas de : (a) complexes pointe-onde, (b) pointes focales". La réglementation française ne comprend que 5 mots sur le sujet :"un électro-encéphalogramme est pratiqué systématiquement". C'est le cas aussi pour toutes

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les autres réglementations. C'est donc dans les instructions techniques qui complètent en cette matière les réglementations officielles qu'il faut aller chercher les directives qui guident les experts.

D'une manière générale, deux principes se dégagent de ces instructions techniques complémentaires de caractère officiel. Nous empruntons leur énoncé aux directives du Service de Santé de l'Air français, parce qu'elles sont particulièrement détaillées.

Premier principe

Un tracé normal classique, montrant, à l'exclusion d'autres rythmes, une activité alpha à 9 ou 10 c/s et à localisation occipito-pariétale symétrique n'est rencontré que chez 40 à 60% des pilotes examinés et dépend en partie de leur tranche d'âge. La notion de normalité doit donc être extensive et l'on doit se garder de normes trop rigides. Néanmoins, des sujets dépourvus d'antécédents pathologiques et cliniquement sains au moment de l'expertise présentent des tracés qui s'écartent de la normalité ainsi définie. La notice technique française relative aux expertises électro-encéphalographiques rappelle à ce sujet que "chez les sujets jeunes, beaucoup plus que d'une affection neurologique cachée ou méconnue, il s'agit d'altérations fonctionnelles en partie liées à l'état physiologique (jeûne, fatigue, manque de sommeil) ou psychique (surmenage intellectuel, anxiété) du sujet au moment de l'examen, mais en partie liées également à l'immaturation, voire à la structuration névrotique de la personnalité. Aucune décision d'élimination ne saurait donc être prise sur le vu d'un EEG et sans tenir compte du contexte clinique".

Deuxième principe

L'électro-encéphalogramme, enregistré lors de l'examen d'admission, trouve une justification comme tracé de référence auquel on comparera les tracés obtenus après des traumatismes crâniens ou dans certains états pathologiques, dans le cours de la carrière de l'aviateur.

En ce qui concerne les conclusions de l'examen électro-encéphalographique, elles sont variables selon qu'il s'agit d'une expertise d'admission ou d'une expertise revisionnelle.

La notice technique française donne aux experts les règles suivantes, pour les examens d'admission :

"a. Seront éliminés définitivement (inaptitude définitive).

" - les sujets porteurs de manifestations électriques paroxystiques, spontanées ou provoquées, évocatrices de comitialité ou au moins d'une potentialité épileptogène importante. Un tracé pratiqué sous sommeil provoqué dont on sait qu'il active souvent les décharges paroxystiques pourra aider l'expert dans sa décision;

" - les traumatisés du crâne porteurs de foyers lents théta ou delta ou de foyers irritatifs séquellaires anciens;

" - les sujets porteurs d'anomalies fonctionnelles importantes, si elles laissent présager une pathologie mentale sous-jacente incompatible avec l'aptitude (à confirmer par psychiatre consultant) ou si elles s'accompagnent de manifestations cliniques avant, pendant ou après l'enregistrement (syncopes vagales, crises tétaniformes, manifestations émotionnelles exagérées);

" - les anomalies focalisées ou généralisées patentes pouvant faire évoquer une atteinte cérébrale d'une origine autre que traumatique;

" - les troubles importants et constants de la vigilance.

"b. Sont déclarés inaptes temporaires :

" - les sujets présentant des séquelles électro-encéphalographiques modérées d'un traumatisme ou d'une affection cérébro-méningée et si l'on juge que ces séquelles sont susceptibles d'amélioration ultérieure;

" - les sujets présentant des anomalies fonctionnelles importantes, mais directement liées à une cause temporaire identifiable : jeûne, fatigue, insomnie, prise de médicament, etc...

" - les sujets trop jeunes ou immatures, dont on peut espérer que l'EEG se normalisera ou se stabilisera avec le temps.

"c. Sont déclarés aptes à titre temporaire :

" - les sujets présentant des anomalies modérées séquellaires d'une affection antérieure ancienne ou des anomalies fonctionnelles dont on veut surveiller l'évolution, sont susceptibles de se voir accorder une aptitude normale, mais sous réserve d'un contrôle semestriel ou annuel;

" - bien que l'EEG soit normal, dans certains cas, l'aptitude peut être limitée dès l'admission en raison d'accidents ou de manifestations cliniques antérieures à l'admission et nécessitant des contrôles de sécurité pendant une période prolongée (2 ans étant un maximum).

"d. Sont déclarés aptes sans réserve :

" - les sujets entrant dans les limites de la normalité électro-encéphalographique conçue de la façon la moins limitative possible.

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Note : "Dans l'état actuel des connaissances, les résultats de l'examen électro-encé-
"phalographique n'entrent pas en ligne de compte pour l'attribution des stan-
"dards propres aux diverses fonctions du Personnel navigant. Les candidats sont
"classés "aptes" ou "inaptes".
"Par exception à cette règle, certains candidats présentant une hypersensibilité
"à la stimulation lumineuse intermittente pourront être déclarés aptes, sauf au
"pilotage des hélicoptères, en raison de l'effet stroboscopique des pales d'hé-
"coptère."

Mais, comme le signale l'Air Vice Marshal O'Connor (12), il ne faut pas oublier que des aviateurs qui développent de l'épilepsie durant le service, peuvent très bien avoir eu des tracés électro-encéphalographiques normaux à leur admission. L'électro-encéphalographie de routine n'identifiera donc qu'une partie des sujets qui constituent un risque élevé pour le développement de l'épilepsie au cours du service. Cet auteur rapporte que sur 10 aviateurs qui présentèrent de l'épilepsie durant le service, trois avaient une anomalie pointe-onde dans leur EEG mais 5 de ces 10 aviateurs avaient un électro-encéphalogramme normal. Néanmoins, l'électro-encéphalographie de routine, malgré ses déficiences, ne peut que réduire ce déchet neurologique en identifiant de mieux en mieux la plupart des candidats qui sont *susceptibles de développer de l'épilepsie.*

Quant à la pathologie neurologique, elle reçoit beaucoup d'importance dans toutes les réglementations. Les listes de maladies et de séquelles de maladies et d'accidents entraînant l'inaptitude présentent une grande concordance. Mais le nombre des éliminations reposant sur une cause neurologique n'est pas important, statistiquement. C'est l'opposé de ce que nous allons voir dans la sélection psychologique et psychiatrique.

B.SELECTION PSYCHOLOGIQUE ET PSYCHIATRIQUE

Les évictions du personnel navigant pour des raisons de nature psychologique et psychiatrique sont faibles en unités opérationnelles, mais très élevées en école de pilotage.

O'Connor (12), faisant état de statistiques relatives à la RAF portant sur 15 années (1958-1973), estime à 2,23 o/oo par année le taux moyen d'éliminations pour affections psychiatriques. Mais, pour les jeunes gens n'ayant pas 20 ans, ce qui est l'âge des élèves-pilotes, les radiations pour des affections ayant fait l'objet d'un diagnostic psychiatrique s'élèvent à 8,4 o/oo. A cette donnée, il faut ajouter une perte constante d'élèves-pilotes pendant l'écolage : le taux de radiations pendant cette période est approximativement de 33%. Dans ce groupe, O'Connor a constaté que 40% de ces échecs relèvent d'une cause psychologique ou psychiatrique. Ainsi donc, selon cette estimation, le nombre total d'inaptitudes survenant en école de pilotage et attribuables à des causes psychiatriques ou psychopathologiques dans le groupe d'âge de 18 à 20 ans s'éleverait à environ 140 o/oo par an (8,4 o/oo + 40% de 330 o/oo).

Ce déchet important se produit en dépit d'un examen psychologique , de tests d'aptitude et d'un examen médical dirigé vers l'observation de données importantes dans l'évaluation du psychisme.

Comment se présente cet examen du psychisme du candidat?

On peut dire que dans toutes les Forces aériennes de l'OTAN, le psychisme du candidat est d'abord étudié à l'occasion de l'examen de médecine générale. Le bilan neuro-psychique, qui est ainsi dressé, est éventuellement complété par un examen neuro-psychiatrique ou de psychologie clinique, pratiqué par un médecin spécialiste en neuro-psychiatrie ou psychologie.

Cet examen d'essence entièrement médicale et demandant beaucoup de temps en raison des interviews et des tests de personnalité est fréquemment complété par des tests qui, très souvent, ne relèvent pas de la responsabilité du Service de Santé. Il s'agit de tests de <u>capacité d'adaptation générale</u> permettant de mesurer le niveau d'intelligence, la rapidité de l'orientation dans l'espace, le degré de cocrdination des 4 membres en réponse à des stimuli sensoriels, les temps de réaction. En outre, on trouve aussi très souvent des épreuves servant à déterminer la <u>capacité de prendre des décisions</u> dans des périodes de temps de plus en plus courtes. Enfin, il existe encore, dans ce groupe de tests échappant à la responsabilité médicale, des épreuves de connaissances scolaires et des tests de psychologie de groupe.

Cette forme d'investigation de la capacité d'adaptation générale et de certains aspects de la personnalité du candidat n'est donc pas régie par des réglementations relevant du Service Médical , bien que très souvent des médecins psychologues y participent et y jouent un rôle très important.

Les méthodes utilisées sont très disparates, d'un pays à l'autre. Il résulte de l'existence de ce système à double responsabilité que l'évaluation du rendement de la sélection psychique globale des candidats pilotes a gagné en difficulté et complexité.

En ce qui concerne l'<u>examen médical proprement dit du psychisme</u>, certaines réglementations médicales sont relativement peu détaillées. D'autres, notamment les réglementations américaines, fournissent des listes très complètes d'affections et d'anomalies entraînant l'élimination.

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La réglementation médicale française présente un aspect original extrêmement intéressant, en ce sens que le texte du sous-chapitre consacré à l'examen du psychisme attire l'attention sur les résultats que l'on peut espérer recueillir dans les trois phases successives de l'examen du candidat, deux d'entre elles relevant de l'examen général et la troisième appartenant à l'examen spécialisé. Pour chacune de ces trois phases, les états qui entrainent l'élimination ou constituent des signes d'alarme sont mentionnés. Cette progression dans la marche de l'investigation aide singulièrement le travail de l'expert dans cet aspect difficile et délicat de la sélection où les états marginaux sont plus fréquents que les états pathologiques bien caractérisés.

Quand les diagnostics sont établis, il est évident que les réglementations américaines facilitent les conclusions de l'expert médical en lui offrant, dans un texte de caractère officiel, le motif précis de l'élimination sous le libellé d'un diagnostic.

Il semble qu'une fusion de l'approche française et de l'approche américaine constituerait un idéal.

A titre de référence, nous donnons ci-après, le texte intégral de la réglementation française :

"Examen psychique :

"L'examen de médecine générale doit s'efforcer de dépister certains antécédents et un "certain nombre de signes cliniques d'alarme.

"a. Etude des antécédents

" Les antécédents sont soigneusement étudiés, après une mise en confiance progressive, excluant tout interrogatoire standardisé.
" Sont systématiquement recherchés :

" (1) Certains antécédents éliminatoires d'emblée :

" - Antécédents psychopathiques personnels : manie, mélancolie, bouffées délirantes, confusion mentale, états schizophréniques, névroses (hystérie obsessionnelle, névrose d'angoisse), perversions, réactions dépressives répétées. Tout sujet ayant subi une thérapeutique en hôpital spécialisé ou en maison de santé psychiatrique est éliminé.

" (2) Certains antécédents qui justifient un examen psychiatrique spécialisé :

" - Antécédents psychopathiques familiaux.

" - Enurésie tardive, somnambulisme passager, terreurs nocturnes, crises ou réactions névropathiques, lipothymies répétées ou d'étiologie imprécise, mal des transports, migraines répétées, bégaiement, instabilité (motrice, émotionnelle ou professionnelle) associée à des réactions impulsives, réactions médico légales, délinquance juvénile, tentative de suicide.

"b. Bilan neuropsychique de l'examen de médecine générale :

" L'examen de médecine générale est l'occasion d'observations sur l'état psychique du candidat, tant sur le plan du niveau intellectuel que sur celui de l'équilibre émotionnel, sur le comportement général et l'attitude. Les observations effectuées, le cas échéant, par les divers médecins-experts du centre sont indiquées à l'expert de médecine générale, qui s'efforce d'en faire la synthèse et adresse, éventuellement, le candidat à un médecin spécialiste de psychologie ou de neuro-psychiatrie.
" Sont considérés comme signes cliniques d'alarme :

" - les bizarreries d'attitude, de comportement;

" - la maladresse excessive, répétée, les signes de débilité motrice, la bradypsychie;

" - l'émotivité exagérée, manifestée par un désordre de la conduite, une inadaptation des réponses aux questions posées, un désarroi dans la situation de l'examen, exprimé soit par une sub-agitation inquiète, soit par une timidité excessive. L'équilibre neuro-végétatif fait l'objet d'une attention spéciale dans la mesure même où il est le reflet de l'équilibre émotionnel : tremblements, rougeurs, pâleur excessive, constante ou passagère, sudations marquées, lipothymie, troubles du rythme cardiaque (extra-systoles, tachycardies sinusales ne se réduisant pas au cours de l'examen, augmentation de la tension artérielle, d'origine neuro-tonique). Ces éléments sont rapprochés des autres éléments cliniques pour fonder la décision de l'expert dans le sens, soit de l'inaptitude d'emblée, soit de l'examen spécialisé.

"c. Examen du spécialiste

" L'examen neuro-psychiatrique spécialisé s'efforce d'aboutir au bilan psychique le plus précis, complété éventuellement par les résultats de tests de personnalité. S'il ne convient pas de définir un type de structure caractérielle univoque d'aptitude au personnel navigant, on doit souligner que l'harmonie de la personnalité est souhaitable, que l'équilibre émotionnel doit être satisfaisant et insister sur la nécessité de l'absence de conflits névrotiques majeurs et d'affections ou de réactions psycho-somatiques. Les personnalités psychopathiques franches et les déséquilibres majeurs sont éliminés.
" L'accent est mis sur l'appréciation de la motivation professionnelle, étant entendu toutefois que certains sujets, dont la motivation est d'allure névrotique, peuvent trouver dans l'aviation un moyen d'équilibrer leur personnalité dans une activité professionnelle satisfaisante.

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" L'expert doit considérer que la fonction de navigant est une fonction de responsabilité individuelle, assumée au cours d'un travail collectif, et que les possibilités d'insertion sociale et d'efficience en groupe des candidats doivent être grandes. Il conclut :

" - soit à l'inaptitude;

" - soit à l'aptitude sans réserve;

" - soit à l'aptitude, complétée de la mention "à surveiller en école sur le plan d'adaptation".

Il est incontestable qu'au cours de ces trente dernières années, un énorme effort a été déployé pour augmenter le rendement des techniques de sélection psychiatrique et psychologique. Le taux des éliminations en école de pilotage est néanmoins demeuré très élevé, comme nous l'avons vu plus haut.

Est-il possible d'espérer une amélioration de la situation par des méthodes plus raffinées?

Il faut d'abord se demander vers quelles méthodes on pourrait se tourner.

Il est généralement admis qu'une anxiété excessive centrée sur l'une ou plusieurs facettes du vol ou sur d'autres aspects générateurs de stress dans la vie de l'élève-pilote constitue l'une des causes les plus courantes et probablement la cause principale qui conditionne les échecs en école de pilotage, par les retentissements défavorables que l'anxiété exerce sur la prise de décision, la concentration de l'attention et la coordination des mouvements.

On peut admettre aussi, comme deuxième cause, que des candidats qui ne sont pas des hyperémotifs ni des inquiets sont des maladroits, malhabiles à réaliser correctement les exercices exigeant une bonne coordination des quatre membres ou des extrémités. Les épreuves psychomotrices insérées dans les programmes actuels de sélection ont pour but d'éliminer les candidats dont le niveau de performance psychomotrice est jugé trop bas. Il ne semble pas qu'il faille encore espérer de gros progrès dans ce dernier domaine. Car, il certain, comme Galle-Tessonneau (13) l'a fait remarquer, que certains candidats ayant subi avec succès ces épreuves psychotechniques ne retrouveront pas en vol le niveau des épreuves de sélection. Il faut donc admettre chez ces élèves une dégradation des performances entre la sélection et le pilotage. En l'absence d'autres facteurs physiologiques ou psychologiques, on peut penser que c'est la situation aéronautique par elle-même qui est responsable de cette détérioration psychomotrice. On peut discuter à perte de vue sur les facteurs qui constituent ce contexte particulier de la situation aéronautique en école de pilotage. En définitive malgré leurs lacunes, on ne voit pas ce qui pourrait se substituer en mieux aux épreuves psychométriques actuellement utilisées en sélection, pour détecter les maladroits non améliorables. Par conséquent, un certain déchet paraît incompressible parce que les faits forcent à admettre, chez certains sujets stables, dépourvus de toute émotivité excessive, l'apparition d'une dégradation psychomotrice en situation aéronautique à l'école de pilotage. Il nous reste maintenant à revenir sur la cause principal des échecs et, par conséquent, le problème essentiel : l'action du stress du vol sur la personnalité de l'élève-pilote.

Les méthodes actuelles de sélection psychologique et psychiatrique tentent de prédire comment un élève-pilote résistera au stress, sur base de ses antécédents. Elles tentent par des interviews et des tests de personnalité ainsi que par une estimation indirecte de l'équilibre neuro-végétatif au cours de l'examen clinique, d'identifier d'une part les sujets qui seront probablement capables de s'adapter au stress du vol, pour autant que leur personnalité n'évolue pas d'une manière imprévue à l'école de pilotage et d'autre part les sujets qui ne seront certainement pas capables de s'adapter à l'anxiété, à en juger par la structure de leur personnalité au moment de l'examen. Ces méthodes ont à leur actif l'élimination de sujets à personnalité pathologique ou fragile. Mais la prédiction favorable portée sur les autres candidats quant à leur succès dans l'adaptation au stress s'avère néanmoins fausse dans un tiers des cas.

Deux voies d'approche se conçoivent, en théorie du moins, pour tenter de porter remède aux insuffisances actuelles.

1. Trouver des mesures physiologiques, de caractère objectif, qui auraient des corrélations élevées avec la capacité de résistance à l'anxiété, ou, à l'inverse, avec une fragilité particulière de l'individu envers l'anxiété. Depuis les débuts de l'aviation, les tentatives faites dans cette direction ont été considérables et en fait, n'ont jamais cessé. Les réponses du rythme cardiaque, de la fréquence respiratoire, de la tension sanguine, des réflexes tendineux, de la coordination des mouvements digitaux, du système vestibulaire, des temps de réaction à des stimuli auditifs et visuels, de la sécrétion des glandes sudoripares de la paume des mains dans différentes situations bien précises ont été prises en considération et souvent intégrées dans des indices dont la valeur a toujours été discutable. Ajoutées aux informations fournies par l'examen clinique et l'examen psychologique classique, ces données ont apporté à l'expert des éléments complémentaires utiles pour l'identification des individus particulièrement fragiles sur le plan de l'anxiété. Mais les corrélations de ces données avec les capacités de résistance au stress du vol n'ont jamais atteint un seuil significatif très élevé permettant de faire réellement fonds sur elles.
   C'est ce qu'indiquaient avec concision mais avec netteté, en 1965, le Group Captain H.H.S. Brown et l'Air Commodore W.K. Steward (14) dans l'introduction générale du

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monumental Text-book of Aviation Physiology, qui reflète les principes mis en pratique au RAF Institute of Aviation Medicine. Je cite : "On doit regarder comme un axiome que les réactions physiologiques aux degrés et types variables de stress ne peuvent pas être évaluées adéquatement au moyen de l'examen clinique seul et les médecins trouveront des variations très larges parmi le personnel navigant en ce qui regarde leur réponse au stress". La cause semblait entendue. Cependant, récemment, les examens biochimiques, tels que la mesure de l'acide vanil-mendélique (Paolucci G et Blundo G. (15)),des catécholamines et d'autres produits hormonaux dans la sécrétion urinaire en réponse à des situations stressantes viennent constituer une autre approche pour tenter de renforcer la valeur prédictive de l'examen de sélection. Malheureusement, il faut bien reconnaître que l'utilisation de ces données lors de l'examen initial de sélection se heurte à des difficultés très grandes dont la principale est de trouver le moyen de placer le sujet dans une situation qu'il considère lui-même comme stressante et qui serait assimilable, en intensité, au stress du vol.

2. L'autre voie consiste à améliorer les instruments de sélection psychologique et psychiatrique, pour obtenir une meilleure connaissance de la personnalité du candidat en matière de résistance à l'anxiété et pour mieux évaluer la solidité de sa motivation pour le vol.
Le nombre de tests mis en application au cours des 30 dernières années est considérable. Ils subsistent plus ou moins longtemps selon la valeur prédictive qu'on leur attribue. Malheureusement le bilan d'un tel effort se mesure à l'épreuve de vérité qu'est le taux d'élimination des candidats pilotes pendant leur entrainement en vol. On peut donc légitimement se demander si des progrès sérieux peuvent encore être espérés dans cette voie.
Tout d'abord, la motivation,dont l'importance capitale dans la carrière de l'aviateur est universellement reconnue, n'est pas un facteur statique. Elle peut varier avec le temps. Le plus souvent, ce sera dans le sens d'une érosion ou de son effondrement. Ses fluctuations dépendent de facteurs sociaux, familiaux, conjugaux, financiers etc... L'âge et le mariage interviennent puissamment comme agents de ces fluctuations, sans qu'il soit nécessaire d'introduire des facteurs relevant de la psychopathologie et de la psychiatrie.
La même instabilité se rencontre dans les réponses aux situations de stress. O'Connor (16) a bien montré dans ses études sur la phobie du vol que l'apparition et le développement du syndrome sont rarement liés à une cause unique et précise. Le plus souvent, on constate une augmentation généralisée dans le niveau de stresses relativement mineurs dans la vie du sujet à un moment déterminé plutôt qu'un traumatisme psychique grave et unique. Une autre difficulté qu'il ne faut jamais perdre de vue, c'est que tout homme, en raison de la complexité du psychisme humain, répond au même stress selon des voies différentes, aux différentes périodes de sa vie.
Ces vues empiriques nous ramènent à un concept pragmatique. Dans le domaine de la personnalité, il n'existe qu'un seul véritable test d'aptitude au vol : c'est le vol lui-même. Entendons-nous bien. Le rejet des candidats qui lors de l'examen clinique général ou neuro-psychiatrique ont présenté dans leur vie passée ou manifestent au cours de l'examen des anomalies nettes, constitue un élément essentiel et efficace de la sélection. Le rejet de candidats dont les réponses sont médiocres aux tests d'aptitude psychologique dont la valeur prédictive est suffisante est également un autre élément essentiel et efficace de la sélection.
Cette double sélection permet d'arrêter au seuil d'une carrière qui ne leur convient pas un lot important de candidats dont les chances de réussite sont nulles ou faibles. Et par conséquent, il faut constamment poursuivre l'effort qui vise à améliorer les techniques de sélection psychologique et psychiatrique. Mais ceci dit, nous ne pouvons pas nous nourrir d'illusions. Ches les sujets qui ont traversé ce premier filtre,parce qu'ils ont été considérés comme répondant aux critères de la normalité, la motivation pourra s'effondrer et la résistance à l'anxiété pourra perdre de sa solidité. Si nous acceptons ces vues, nous devons nous résigner à admettre - et surtout à faire admettre par les Etats-Majors - deux faits importants :

   a. Environ 35% des candidats que le Service Médical a déclarés aptes à l'entraînement en vol seront éliminés au cours de cet entraînement pour des raisons qui, derrière le voile trompeur du vocabulaire utilisé par les moniteurs, relèvent dans leur majorité de l'anxiété et de l'hyperémotivité.
   Cette perte d'un tiers des élèves-pilotes, nous devons l'accepter parce que nous sommes impuissants à la réduire par nos méthodes actuelles de travail.

   b. En ce qui concerne les aviateurs expérimentés, en service en unité, on doit s'attendre aussi à un certain taux de perte, pour des motifs psychologiques et psychiatriques. Le taux annuel de perte se situe, en temps de paix, entre 2 à 3 o/oo. Il est donc très faible. Il semble lui aussi incompressible malgré les efforts de la surveillance médico-psychologique en unité.

Un énorme champ de recherches demeure donc largement ouvert à la psychologie et à la psychiatrie aéronautiques, dès la phase initiale de sélection et jusqu'aux abords du terme normal d'une carrière aéronautique. Tout progrès, si minime soit-il, représentera toujours des économies substantielles.

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III. SELECTION ET AVIATION MILITAIRE DE L'AVENIR

Toute évolution dans les conceptions de l'avion de combat ouvre la porte à des modifications dans la signification de certaines anomalies ou insuffisances morphologiques, physiologiques et sensorielles, soit dans le sens d'une réduction de leur importance pour certaines d'entre elles, soit dans le sens d'une augmentation de cette importance pour d'autres.

Nous considèrerons brièvement deux facettes de ce problème:

1. Est-il rentable, sur le plan médical, de sélectionner des candidats aviateurs pour les destiner d'emblée, d'une manière définitive, à des types déterminés d'aéronefs (avions de combat, avions de transport, hélicoptères, etc...).

2. Devra-t-on hausser la sévérité des critères d'admission pour les pilotes des avions de combat de la nouvelle génération? Faut-il créer pour eux une sorte de superstandard?

   a. Est-il rentable de sélectionner des candidats aviateurs destinés d'emblée, d'une manière définitive, à des types déterminés d'aéronefs (avions de combat, avions de transport, hélicoptères, etc...)

   Dans les textes des 9 réglementations que nous avons étudiées, il n'est jamais question, pour les candidats pilotes, de critères spécifiques adaptés à des types particuliers d'aéronefs.

   Il semble que le seul domaine médical qui pourrait être envisagé pour répondre à la question posée et atténuer le pourcentage d'éliminations chez des candidats bien motivés pour l'aviation devrait se limiter à celui de la vision.

   Dans ce cas, une solution se présente à l'esprit immédiatement, parce qu'elle offre des données d'appréciation qui sont presque expérimentales. Les critères de vision pourraient être abaissés pour les candidats pilotes d'hélicoptère et les candidats pilotes d'avion de transport et être ramenés aux critères de vision n°1 de la Luftwaffe appliqués à tous les candidats pilotes (candidats pilotes d'avion et d'hélicoptère), parce-que ces critères sont les plus bas de ceux utilisés dans les Forces aériennes de l'OTAN? Ce critère de vision n°1 dit que l'acuité visuelle, mesurée avant l'instillation d'un cycloplégique, doit être égale à 5/10 au moins, corrigible à 10/10 pour chaque oeil pris isolément. Quand des verres correcteurs sont nécessaires pour atteindre 10/10, leur port est obligatoire pendant l'exécution des vols. Une paire de verres de réserve doit être disponible. L'utilisation de lentilles de contact n'est pas autorisée.

   Les types de missions effectuées en hélicoptère ou en avion de transport, les caractéristiques du poste de pilotage, notamment en ce qui concerne le port aisé de verres correcteurs à 2 ou 3 foyers, permettraient cette solution sans porter atteinte à la sécurité du vol et à l'efficacité de la mission. L'expérience de nos collègues de la Luftwaffe serait d'un appoint extrêmement précieux pour porter un jugement sur les avantages et désavantages, proches ou lointains, de la politique adoptée présentement en République Fédérale d'Allemagne, non seulement pour les candidats pilotes d'hélicoptère, mais aussi pour tous les candidats pilotes d'avion et par conséquent ceux qui sont devenus pilotes de transport et pilotes d'hélicoptère.

   Nous croyons cependant que la politique de rigueur à l'admission, suivie par la majorité des Forces aériennes de l'OTAN, présente deux avantages importants, de nature médicale, qu'il convient de mettre en balance avec des facteurs extra-médicaux de disponibilité d'un nombre plus grand de candidats, si l'on abaisse ces critères. La politique de rigueur offre la possibilité de réserver en priorité l'accès aux fonctions de pilote d'hélicoptère ou d'avion de transport à deux catégories de pilotes expérimentés c'est-à-dire des pilotes pour lesquels les frais énormes de la formation, de l'entraînement et de l'acquisition de l'expérience sont déjà justifiés par la réussite dans la carrière navigante. Ces deux catégories de pilotes sont :

   (1) les pilotes qui, à cause d'un accident ou en raison de l'évolution naturelle liée à l'âge, subissent en cours de carrière une réduction de l'acuité visuelle peu compatible avec celle requise pour les missions de combat;

   (2) les pilotes qui, bien que jouissant d'une acuité visuelle normale, et après un séjour suffisamment prolongé en unité de chasse ou de bombardement, ne manifestent pas une personnalité de chasseur ou de bombardier, mais présentent une motivation saine et des traits caractériels plus propices à l'accomplissement des missions de transport ou des missions dévolues aux hélicoptères.

   Nous avons rétréci ce problème uniquement à des aspects de vision. Le problème est certainement beaucoup plus vaste. Une étude plus approfondie mériterait d'être faite : elle découvrirait peut-être certains aspects médicaux qui dépassent en importance les seules conditions ophtalmologiques qui ont été considérées maintenant.

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b. Faut-il envisager un superstandard pour les pilotes des avions de la nouvelle génération?

L'électronique prend actuellement une part grandissante dans la conduite de tous les types d'aéronefs, surtout dans celle des avions de combat de la nouvelle génération. Elle ne supprime pas ni ne diminue pas le rôle du pilote humain ou de l'équipage. Loin de là. L'avenir seul nous dira bientôt dans quelle mesure pourrait être modifié le degré d'importance de certains facteurs sensoriels dans le pilotage. Le pilote de l'avion de combat doit recueillir des informations de plus en plus abondantes sur son tableau de bord. Il doit les interpréter très vite et les intégrer très vite. Piloter est une chose. Répondre aux exigences de la mission et l'accomplir avec efficacité sont une autre chose. Nous n'avons aucune raison de croire que l'accomplissement des missions aériennes confiées aux nouveaux avions de combat sera moins exigeant en ce qui concerne les fonctions sensorielles , tout particulièrement la fonction visuelle. Il suffit de songer aux missions de pénétration à basse altitude et grande vitesse.
En ce qui concerne les effets des missions sur les fonctions cardio-vasculaire et respiratoire et sur tout ce qui concourt à l'éclosion de la fatigue physique et mentale, surviennent immédiatement, à l'avant-plan des préoccupations, les effets des accélérations + Gz de longue durée et, du côté psychique,les effets d'une attention intense, sans le moindre relâchement. Ces considérations justifient-elles un superstandard?

Le problème de la création éventuelle d'un superstandard pour les pilotes des avions de haute performance nous paraît mal posé. Selon nous, il ne s'agit pas d'un problème de sélection médicale, mais plutôt d'une question de forme physique et mentale à entretenir et à contrôler en unité. En effet, toutes les réglementations exigent, d'une manière générale, l'intégrité anatomique et fonctionnelle des appareils et organes par lesquels s'exerçent les grandes fonctions. Cette intégrité signifie la normalité en tout, sauf quelques anomalies morphologiques mineures ou certaines séquelles sans importance d'intervention chirurgicale, de traumatisme ou d'accident. On ne voit donc pas comment on pourrait dépasser ce stade de normalité déjà exigé, sans provoquer un tarissement dramatique du recrutement.

Toutefois, sur certains points où les limites qui cernent le concept de la normalité sont assez floues, certaines précisions pourraient être apportées, dans le sens restrictif, pour s'assurer que le candidat possède effectivement et à suffisance, au moment de la sélection initiale, un capital de départ que l'entraînement sera chargé d'amplifier, puis d'entretenir d'une manière adéquate.

Je vois 3 points particuliers où des précisions dans le sens d'exigences plus nettes ou plus rigoureuses pourraient être réclamées, si elles n'existent déjà pas, pour les futurs pilotes des avions de combat de la nouvelle génération.

(1) La capacité d'adaptation générale

Le problème des aptitudes humaines a pu être ramené, en matière de sélection psychologique des aviateurs, à un nombre réduit de facteurs de base permettant de décrire les capacités d'un sujet. Guilford, par exemple, a pu ramener à quatre facteurs ce qu'il a appelé la capacité d'adaptation générale: facteur verbal, facteur numérique, facteur spatial, capacité d'adaptation sociale.

Des tests de performance permettent de vérifier les aptitudes des candidats en ces domaines. Il semblerait donc qu'en haussant prudemment le seuil de performance requis pour les normes des aptitudes d'adaptation générale chez les candidats, on répondrait déjà, par le simple jeu des méthodes psychométriques, à des exigences particulières éventuelles de la nouvelle génération d'avions, si ces exigences existent réellement dans ce domaine particulier. Rien n'est moins sûr. Tout reste à démontrer.

(2) La stabilité émotive

Il ne s'agit que d'une interprétation plus stricte, si besoin en est, du niveau de la normalité, dans le résultat des tests de personnalité et des techniques utilisées en psychologie clinique et psychiatrie, principalement pour mettre en évidence des tendances psychopathologiques chez des sujets apparemment normaux. Nous avons montré plus haut les difficultés rencontrées actuellement sous ce rapport.

(3) La forme physique et la résistance aux accélérations prolongées, à un effort prolongé et à la fatigue.

Il n'y a là rien de neuf. L'application d'épreuves d'endurance permettant d'évaluer la résistance cardio-vasculaire et respiratoire à un effort prolongé et épuisant permet lors de la sélection initiale de n'accepter que des sujets disposant déjà d'un degré très satisfaisant de ces qualités, au début de leur carrière. Dans la plupart des Forces aériennes, cet objectif est déjà atteint par des épreuves d'effort de types divers (épreuves sur bicyclette ergométrique, épreuves sur tapis roulant, step-tests étalonnés etc...) et par des épreuves fonctionnelles respiratoires. On se reportera à ce sujet à l'Agardographien° 196, publiée sous la direction du Médecin-Général Scano (17). Tout autre chose est l'importance accordée à l'entretien d'une bonne forme physique. Elle se concrétise dans les Unités navigantes des Forces aériennes

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par l'emploi périodique de tests de contrôle auxquels le Personnel navigant doit se soumettre. Par exemple, le test de Cooper (une course de 2.400 mètres sur terrain herbeux en moins de 12 minutes) est pratiqué à l'USAF, à la RAF et a fait l'objet d'une expérience en septembre 1976 aux Pays-Bas (18). La Luftwaffe, pour l'entretien de la forme physique de ses pilotes, utilise le système de Hill (programme journalier d'exercices durant 8 minutes avec contrôle du temps réalisé pour chaque série d'exercices). Il appartient donc au Commandement, avec les avis techniques de son service médical, de favoriser et surveiller les méthodes d'éducation physique et les pratiques sportives, individuelles et collectives, qui doivent entretenir et améliorer la forme physique du personnel navigant. Il lui appartient aussi d'en assurer le contrôle par des tests adaptés à ce genre d'évaluation. Au moment de la sélection, il paraît normal qu'il soit exigé des futurs aviateurs, appelés à voler sur des avions de haute performance, qu'ils fassent la preuve qu'ils possèdent déjà un niveau suffisamment élevé de forme physique.

Ce sera, au surplus, un test indirect de leur motivation.

Si l'on considère le problème sous cet angle, on ne distingue pas de raisons plausibles pour déplacer vers une plus grande sévérité les prescriptions réglementaires actuelles à l'admission et aux examens révisionnels, ni surtout pour créer un superstandard, en ce qui concerne les aviateurs qui devront piloter les avions de combat de la nouvelle génération. Le problème intéresse davantage l'entraînement que la sélection.

IV. RECRUTEMENT DE CANDIDATS PILOTES MILITAIRES DU SEXE FEMININ

La dynamique des idées actuelles ouvre aux femmes l'accès aux Ecoles militaires et leur offre un nombre croissant de fonctions dans les Forces armées. Il convient donc de porter une attention particulière au problème des critères médicaux de sélection applicables aux personnes du sexe féminin, candidates à des fonctions de pilote d'aéronefs militaires.

Comment se présentent actuellement les réglementations relatives aux critères de sélection sous ce rapport?

Elles sont marquées par une certaine ambiguité.

Les réglementations américaines détaillent les affections gynécologiques entraînant l'inaptitude au vol sous la rubrique de la Flying Class 3, en surplus de la rubrique "Enlistment and Commission". On ne trouve aucune mention relative aux affections gynécologiques, dans les critères intéressant les Flying Classes 1 and 2. Ceci signifie-t-il que ces réglementations n'ont été conçues, en ce qui se rapporte au personnel féminin, que pour des infirmières de l'Air ou des convoyeuses de l'Air et non pour des élèves-pilotes ou du personnel exerçant des responsabilités de conduite d'un aéronef? Il le semblerait. D'autres réglementations fournissent, dans la section relative à l'aptitude générale au service militaire, la liste des affections gynécologiques entraînant l'inaptitude. Mais dans la réglementation spécifique à l'aptitude au service navigant, elles sont muettes ou se bornent à quelques généralités qui répètent l'une ou l'autre de ces dispositions relatives au service militaire en général (réglementation de la RAF).

Pour ce qui rapporte à la grossesse, elle est citée comme cause d'inaptitude temporaire dans les réglementations américaines, la réglementation canadienne, la réglementation norvégienne et la réglementation britannique. Les autres réglementations sur l'aptitude au vol sont silencieuses sur ce point. Sans aucun doute, faut-il se rapporter à des instructions particulières, distinctes du cadre officiel des réglementations d'aptitude au service navigant et applicables, d'une manière générale, à tout le personnel féminin.

On peut donc résumer la situation dela manière suivante.

Les textes des réglementations militaires d'aptitude au vol prévoient des dispositions particulières s'appliquant aux infirmières de l'Air et aux convoyeuses de l'Air. Mais, pour les fonctions de pilote, navigateur, mécanicien de bord, radiotélégraphiste de bord, on ne trouve aucune référence particulière au personnel féminin, à des affections gynécologiques ou à des états liés plus particulièrement à la constitution féminine et dont il y aurait lieu de tenir compte.

Du côté de l'Aviation civile, les conditions d'aptitude physique et mentale n°1 recommandées par l'OACI pour les licences civiles de pilote présentent à l'alinéa 6.2.1.24 un texte très général relatif au personnel féminin :

"Les candidates qui présentent des antécédents de troubles menstruels graves, réfrac-
"taires à tout traitement, qui peuvent les gêner dans la conduite d'un aéronef au
"point d'en compromettre la sécurité, seront déclarées inaptes. En cas de grossesse
"présumée, la candidate sera déclarée temporairement inapte. Après accouchement ou
"avortement, la candidate ne sera autorisée à exercer les privilèges de sa licence
"qu'après avoir subi un nouvel examen médical et avoir été déclarée apte".

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La recommandation 6.2.1.24.1 dit :

"il est recommandable de considérer individuellement les cas des candidates ayant subi "des opérations gynécologiques".

Les mêmes textes se retrouvent dans les conditions d'aptitude physique et mentale n°2.

Les conditions d'aptitude physique et mentale n°1 de l'OACI, lorsqu'elles sont satisfaites, permettent donc l'octroi au personnel féminin des licences civiles suivantes :

- pilote professionel avion;
- pilote professionnel de première classe-avion;
- pilote de ligne-avion;
- pilote professionnel-hélicoptère;
- pilote de ligne-hélicoptère.

Les conditions d'aptitude physique et mentale n°2 permettent l'octroi des licences civiles suivantes :

- navigateur;
- mécanicien navigant;
- opérateur radio-navigant.

Sur le plan des principes, il ne semble donc pas que des critères médicaux précis fassent matière à difficultés en procédant par assimilation à ce qui est autorisé dans l'Aviation civile, c'est-à-dire l'accès des femmes militaires aux fonctions navigantes similaires à celles ouvertes dans l'aviation civile de transport. Si tel est le cas, on pourrait suggérer, pour éliminer toute équivoque, que des textes clairs, précis, détaillés sur les affections gynécologiques et autres conditions propres à la constitution physique et au psychisme des personnes du sexe féminin figurent, eux aussi, dans les réglementations militaires relatives à l'aptitude aux fonctions mentionnées ci-dessus, qui toutes se rapportent à des missions de transport de personnel ou de matériel.

Faut-il aller plus loin et prévoir l'application de critères de sélection pour des vols sur tout type d'aéronefs militaires c'est-à-dire pour des fonctions combattantes, des fonctions de moniteur de vol, d'essayeur en vol d'avions de combat, ou, plus simplement l'aptitude comme candidat pilote toutes catégories, selon la terminologie française ou encore l'aptitude à la Flying Class I, selon la terminologie américaine?

Une étude attentive de ce problème, sous l'angle des capacités physiques et mentales, devrait être entreprise. Il paraît opportun de la faire sans tarder en tenant compte des exigences opérationnelles maxima qu'implique l'accomplissement des divers types de missions aériennes en milieu militaire en temps de paix et surtout en temps de guerre, pour du personnel féminin. On ne perdra pas de vue, pour autant, l'implication d'autres aspects, notamment ceux relatifs au Droit humanitaire international (Conventions de Genève du 12 Août 1949 et Protocoles additionnels à ces Conventions, de juin 1978), dans ses dispositions relatives à la protection juridique des personnes du sexe féminin, en temps de conflit armé. Ces recherches permettraient de dissiper les ambigüités des réglementations actuelles manifestement rédigées pour des hommes, quand il s'agit de postes à responsabilité de conduite, à bord d'avions de combat. Ces recherches aboutiraient probablement à suggérer des compléments ou des réajustements mieux adaptés à la constitution de la femme, dans un domaine lourd de responsabilités: celui de l'aptitude au vol sur les divers types d'aéronefs militaires, aux postes de conduite de ces aéronefs, dans les missions militaires variées que l'on peut rencontrer dans une Force aérienne opérationnelle.

C'est par cette échappée vers un nouveau champ de recherches, offert aux investigations des Services de Santé de l'Air, que je clôture cette rapide revue de quelques problèmes relatifs aux réglementations médicales de sélection des aviateurs militaires.

Les concepts et les textes relatifs aux critères médicaux d'aptitude au vol semblent, au premier abord, relativement figés, parce qu'ils prennent la forme sévère, quasi hiératique, des réglements militaires. Mais tous les monuments aux apparences les plus solides ont toujours l'un ou l'autre pan qui, plus fragile, mérite réparation ou qu'il conviendrait d'adapter à une nouvelle fonction. Force est de reconnaître, quand on compare minutieusement dans tous leurs détails les réglements d'aptitude des Forces aériennes de l'OTAN, que certaines de leurs dispositions, parfois consacrées par la tradition, n'ont plus qu'une valeur douteuse, et que d'autres, en raison de leur importance, mériteraient qu'un effort soit consacré à l'unification de leurs données numériques dans les Forces aériennes de l'OTAN. D'autres dispositions sont ouvertes à l'évolution : leurs modifications portent sur des détails, souvent très importants dans leurs conséquences, et sont le reflet de progrès récents dans les connaissances médicales et dans les techniques médicales d'expertise.

Et enfin, il reste le bloc des matières classiques qui forment l'armature des réglements. Celles-là aussi, malgré leur respectable et vénérable solidité, exigent d'être reconsidérées périodiquement, dans leur globalité, à la lumière des faits - qui sont plus forts que les théories - et surtout à la lumière des résultats des recherches. Celles-ci placées entre les mains de chercheurs qualifiés, aidés d'experts chevronnés en ces matières spéciales et difficiles, sont seules capables d'offrir des solu-

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tions meilleures à certaines questions qui n'ont jamais reçu de réponses vraiment satisfaisantes depuis que l'on recrute et sélectionne des candidats pilotes.

Les quelques problèmes qui n'ont été que sommairement évoqués montrent à suffisance que les besoins de recherches ne manquent pas dans ce domaine.

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DISCUSSION

K. Klein — Will you explain in greater detail your comments regarding the use of contact lenses?

E. Evrard — The regulations of all nine countries that were reviewed forbid the use of contact lenses at the time of the initial examination. At later examinations, however, some Air Forces, the French Air Force and the RAF for example, allow the use of contact lenses, but only for limited duty and only with the specific permission of an ophthalmologist.

J. Meunier — I should like to tell you of our present position regarding female pilots. After carefully reviewing our experience, we have concluded that the only important difference relates to the performance problems associated with pregnancy and occasionally with menstruation. In some female pilots the symptoms associated with menstrual periods are so severe that flying must be precluded. With each pregnancy there will be several months when a woman cannot fly, and in addition, a re-training period is required before return to full duty. In military aviation in France, to my knowledge, there are no women pilots presently on flying duty. In commercial aviation we have two airline pilots who are performing well.

E. Evrard — It seems to me that there are two actions that we must take regarding female pilots: 1) to give women the opportunity to become pilots; 2) to find out which, if any, flying duties women are not able to perform satisfactorily.

AN ADVANCED OXYGEN SYSTEM FOR FUTURE COMBAT AIRCRAFT

by

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SUMMARY

The operational and physiological requirements for an Advanced Oxygen System for future high performance combat aircraft are considered and reviewed. It is concluded that such an oxygen system should employ a molecular sieve on board oxygen generation system, pressure premix for dilution of the oxygen by air and a twin demand regulator package. The principles of operation of such a system are considered and a design is proposed.

INTRODUCTION

For the first two decades after World War II, ie from 1945 to 1965, the oxygen systems fitted to the combat aircraft of most NATO Air Forces stored oxygen in the liquid form (LOX) and controlled the delivery of oxygen, mixed in many applications with air, to the oronasal mask worn by the aircrew by a panel or body mounted pressure demand regulator. Oxygen is still almost universally carried in NATO combat aircraft as LOX. High pressure gaseous storage is used for emergency supplies and in certain training aircraft. The operational importance of flight at very high altitudes in the period from 1955 to 1965 necessitated the widespread use of partial and full pressure suits where the oxygen regulator was mounted on the aircraft, on the ejection seat, in the survival pack or on the body or head of the wearer. Whilst the conventional panel mounted oxygen regulator is still widely employed today in NATO combat aircraft several countries especially France, the United States (the United States Navy) and the United Kingdom explored, developed and introduced into service in the 1960s, oxygen systems for routine use at altitudes below 50,000 feet in which the regulator was mounted either on the ejection seat or on the aircrew. Thus the United States Navy adopted a miniature 100% oxygen regulator mounted directly in the mask, the Royal Air Force and Royal Navy adopted a body mounted dilution regulator mounted on the front of the torso and the French Air Force and the Royal Air Force adopted a dilution regulator mounted on the ejection seat. The latter site for the oxygen regulator has been favoured by the UK Development Agencies since the early 1960s (it was used in the TSR2) and it has been adopted by the German and Italian Air Forces as well as the Royal Air Force in the Tornado.

The performance and logistic requirements of the conventional LOX storage and current generation of air dilution pressure demand regulator oxygen systems make these systems unsuitable however for use in the new combat aircraft under development for the NATO Air Forces especially when the manner in which these aircraft will be used in the 1980s and 1990s is taken into account. The major deficiencies in this context of the conventional pressure demand systems and even of the new systems about to be introduced into service (eg in the Tornado) are the use of LOX, the high rate of consumption of oxygen and the need to provide a separate breathing system for operations conducted in a chemical warfare (CW) environment. Conventional panel mounted pressure demand oxygen systems have, in addition, the disadvantages that they impose a relatively high impedance to respiration and do not incorporate the desirable duplication of essential components. Furthermore, those systems do not provide the new facilities such as pressure breathing on exposure to sustained positive acceleration which may well be required in the combat aircraft of the 1990s.

The requirements for and a possible design of Advanced Oxygen System for combat aircraft of the late 1980s and the 1990s are considered in this paper. The performance requirements of such an Advanced Oxygen System are derived from considering the operational characteristics and use of the new combat aircraft and reviewing, where appropriate, the deficiencies of current conventional oxygen systems. The correct compromises with respect to the physiological requirements for an Advanced Oxygen System are also considered. Taking account of recent and current developments in the design of oxygen generating and oxygen control systems the design of an Advanced Oxygen System is proposed.

OPERATIONAL REQUIREMENTS

Aircraft performance

The operational ceiling of future combat aircraft will generally be less than 50,000 feet. Flight to altitudes greater than 50,000 feet will probably occur very seldom and even then will generally take the form of a zoom manoeuvre with the time at altitudes above 50,000 feet being limited to only a few minutes. Pressure clothing will therefore not be required except on rare occasions. An Advanced Oxygen System should therefore provide protection against hypoxia at altitudes up to 50,000 feet. If pressure clothing is required then a partial pressure suit of the bladder type (6) probably represents the best compromise. Should this form of high altitude protection be required it should be possible to select the pressure breathing-altitude schedule appropriate to the personal equipment in use.

Future combat aircraft will certainly be highly manoeuvrable and capable of sustaining turns giving positive accelerations of the order of 8-9 G for many seconds. Thus the aircrew will require enhanced protection against the impairment of performance produced by exposure to high sustained $+G_z$ (3). Whether this enhanced tolerance is produced by improvements in the conventional G trouser system or by reclining the aircrew in the aircraft, positive pressure breathing will be required to prevent the gross disturbances of pulmonary function produced by exposure to high levels of $+G_z$ (9). An Advanced Oxygen System should therefore be capable of supplying pressure breathing on exposure to sustained positive acceleration.

Operational environment

Future combat aircraft will be operated primarily from Hardened Aircraft Shelters. Aircrew will be required in certain roles to remain at standby in their aircraft for several hours. The ability to generate and sustain a high sortie rate will be of great importance. It is highly desirable that the procedures which have to be carried out during aircraft turn around on the ground should be reduced to a minimum. Thus the amount of recharging equipment and fresh stores required within the Hardened Aircraft Shelter should be minimised. Very considerable logistic and operational advantages would accrue from elimination of the need to replenish the aircraft oxygen store. These considerations apply even more forcibly to aircraft such as the Harrier which can be operated away from a main airfield. Thus an Advanced Oxygen System should employ on board generation of oxygen by a system which does not require replenishment or servicing during routine turn around of the aircraft.

It is very likely that aircrew operating combat aircraft in a future war will be exposed to attack with chemical warfare (CW) agents. The enemy is very likely to attack fixed air bases with persistent and non persistent CW agents and aircrew will be required to operate aircraft which are or may become contaminated with CW agents. An Advanced Oxygen System should therefore provide protection to the respiratory tract against the inhalation of CW agents. It is desirable also that the System provides CW agent free gas (air) to purge the eye space of the aircrew respirator.

Cabin Pressurisation

Low pressure differential pressure cabins will continue to be used in high performance combat aircraft in order to minimise structural weight and susceptibility to damage of the aircraft and its occupants on penetration of the cabin by missiles or portion of missiles. Thus the maximum pressure difference across the wall of the cabin will be 4.5-5.0 Lb in^{-2}. The cabin altitude of a future combat aircraft will be such therefore that the oxygen system will be used throughout flight.

Oxygen system

Important general requirements with respect to the oxygen system for a future combat aircraft are that the system should be simple to operate, reliable, easy to maintain and require the minimum of logistic support. Finally, the unit cost of the complete system should be as low as possible. Although reliability, maintainability and low cost are often most easily achieved by simplicity of design, the performance requirements may limit the degree to which the system can be simplified as compared with the sophisticated oxygen systems recently introduced into service in aircraft such as the Tornado.

OXYGEN CONCENTRATION AND CONSUMPTION

Current conventional pressure demand oxygen systems are very wasteful of the oxygen store carried in the aircraft. In the past the replacement of high or medium pressure gaseous storage systems by LOX converters removed partly the need to have great economy in the rate of use of oxygen and so only sporadic attempts have been made to devise oxygen systems in which the rate of consumption of oxygen is minimised. The requirement however to avoid the logistic and operational penalties of an aircraft oxygen store which has to be replenished by recharging on the ground by the use of an onboard oxygen generation system has revived the need to define the minimum rate at which oxygen must be supplied to aircrew in flight. In an open circuit system the rate at which oxygen is consumed is a function of the pulmonary ventilation and the concentration of oxygen delivered by the system to the mask.

Pulmonary Ventilation in Flight

There is only a limited amount of data relating to the pulmonary ventilation of aircrew operating high performance combat aircraft. Until very recently the standard USAF references (MIL-D-1932E June 1971 and MIL-D-8683A) were based on a pulmonary ventilation meaned over the whole sortie of 14.5 $\ell(BTPS)min^{-1}$. With the introduction of pressure demand oxygen regulators into the Royal Air Force in the early 1950s it was soon found that this figure for the mean pulmonary ventilation was too low. Following measurements of bottle oxygen consumption in flight in a wide variety of combat aircraft a pulmonary ventilation of 23 $\ell(BTPS)min^{-1}$ was adopted for predicting the oxygen consumption for the pilot of a single seat aircraft (to include 97% of occurrences) (2). The corresponding pulmonary ventilation per man for 2 or 3 crew aircraft was 19.7 $\ell(BTPS)min^{-1}$, and for 4 or more crew aircraft was 17.1 $\ell(BTPS)min^{-1}$.

In the last few years measurements of the pulmonary ventilation of pilots flying combat aircraft have been made both in the US (13) and UK (10). These studies have provided quantitative data on the increase in pulmonary ventilation associated with certain phases of flight such as take-off, landing and air-to-air combat. Thus in mock air-to-air combat it was found for a group of 12 pilots that the mean pulmonary ventilation was 26 $\ell(BTPS)min^{-1}$ with a range of 19 to 50 $\ell(BTPS)min^{-1}$.

The US data has recently be consolidated into an amendment of MIL-D-19326. This employs baseline maximum pulmonary ventilations (for 90% of occurrences) of 17.5 $\ell(BTPS)min^{-1}$ for a single pilot and 16.1 $\ell(BTPS)min^{-1}$ for each of a two man crew. The amended specification states that this baseline pulmonary ventilation is increased by 75% in aerial combat and by 25% in terrain following. Assuming that the pilot will be involved in air-to-air combat for 1/3rd of a sortie, the pulmonary ventilation for a single pilot predicted by the amended MIL specification is 21.8 $\ell(BTPS)min^{-1}$. This analysis suggests that there is now little difference between the US and UK data relating to the pulmonary ventilation to be used for the calculation of the amount of oxygen required during a typical combat sortie. The existing UK specification (pulmonary ventilations of 23.0 and 19.7 $\ell(BTPS)min^{-1}$ per man for single and two crew aircraft respectively) will therefore be used in this paper.

The maximum pulmonary ventilation which can be sustained for longer than 30-60 seconds in flight is also of importance. This quantity will influence the size of the capacity which must be placed between an onboard oxygen generating system and the user to ensure that sufficient breathing gas is available for the

periods in flight when the pulmonary ventilation exceeds the mean for the complete sortie. The inflight data obtained by RAF IAM (10) suggest that the maximum pulmonary ventilation which may be sustained in flight for longer than 30 sec is 40 $\ell(BTPS)min^{-1}$.

Concentration of oxygen in the inspired gas

The concentration of oxygen in the gas delivered by an oxygen system is an important factor in determining the rate at which the oxygen supply is consumed. The relationships between the rate of consumption of oxygen and cabin altitude for a pulmonary ventilation of 23 $\ell(BTPS)min^{-1}$ for open circuit air dilution demand systems which maintain alveolar oxygen tensions equal to those associated with breathing air at ground level and altitudes of 5000 and 8000 feet (with an alveolar carbon dioxide tension of 38-40 mm Hg) are presented in figure 1. The practical implications in terms of oxygen economy in requiring that the oxygen delivery system delivers air/oxygen mixtures which will maintain the equivalent of breathing air at 5000 or 8000 feet rather than ground level are very apparent. Thus at a cabin altitude of 15,000 feet the rate of oxygen consumption is reduced by 60% by diminishing the oxygen concentration in the gas delivered to the respiratory tract from that required to maintain a ground level alveolar oxygen tension to that which will produce an alveolar oxygen tension equal to that when breathing air at 5000 feet. Also shown in figure 1 is the rate of consumption of oxygen in a system employing a conventional injector dilution demand regulator. The great waste of oxygen produced by this form of regulator is readily apparent.

The relationship between the minimum concentration of oxygen in the inspired gas and cabin altitude is of great significance in the design of an Advanced Oxygen System where economy in the use of oxygen will almost certainly be of major concern. A detailed review of the maximum acceptable degree of hypoxia in flight reported elsewhere (7) has led to the conclusion that the oxygen tension in the gas entering the lungs (tracheal) should be 122 mm Hg (equivalent to breathing air at an altitude of 5000 feet) or greater. The relationship between cabin altitude and the concentration of oxygen in the inspired gas required to maintain the equivalent of breathing air at 5000 feet is given in figure 2.

A further factor which influences the relationship between the concentration of oxygen in the inspired gas and cabin altitude is the need to prevent impairment of performance due to hypoxia following a failure of the pressure cabin at high altitude. The fall of the total pressure of the alveolar gas produced by rapid decompression of the cabin of an aircraft at altitude produces a concomitant reduction of the alveolar oxygen tension (P_{O_2}) which may be to such a level that it produces impairment of performance or even unconsciousness. If the decompression is to an altitude greater than 30,000 feet then 100% oxygen must be delivered to the respiratory tract immediately the decompression occurs if there is not to be a significant impairment of consciousness. There will be a significant impairment of performance if the alveolar P_{O_2} is reduced during the decompression to below 30 mm Hg even for a very short period of time. The oxygen delivery system should therefore prevent the alveolar P_{O_2} falling below 30 mm Hg as a result of a rapid decompression (for this purpose the maximum altitude produced by a decompression can be considered to lie between 38,000 and 44,000 feet, depending upon the pressure breathing/pressure suit system in use). The major factors determining the minimum value of the alveolar P_{O_2} after a rapid decompression are the initial and final cabin altitudes, and the composition of the gas breathed before and after the decompression. Assuming that 100% oxygen is delivered to the respiratory tract immediately the decompression occurs the alveolar P_{O_2} may be prevented from falling to below 30 mm Hg by ensuring that a certain minimum concentration of oxygen is breathed when the pressure cabin is intact. The concentration of oxygen required will vary with the initial and final cabin altitudes, as shown in figure 2 (interrupted lines indicate cabin altitude after decompression). It is then possible, knowing the normal relationship between cabin and aircraft altitude with the cabin pressurised, to describe a curve which indicates the minimum concentration of oxygen required to prevent the alveolar P_{O_2} falling below 30 mm Hg on decompression of the cabin. The solid curve in figure 2 indicates this relationship for a typical combat aircraft (with a maximum cabin differential pressure of 5.0 Lb/in^{-2}).

The limit for the maximum concentration of oxygen acceptable in the inspired gas is set by considerations of the incidence of lung collapse (acceleration atelectasis) on exposure to sustained $+G_z$ (5) and delayed otitic barotrauma (11) produced by the absence of an adequate concentration of nitrogen (or other physiologically inert and relatively insoluble gas). It is highly desirable that the concentration of nitrogen in the inspired gas does not fall below 40%, ie that the concentration of oxygen in an air/oxygen mixture does not exceed 60% (5).

Various changes to the relationship between the concentration of oxygen in the inspired gas and cabin altitude shown by the heavy line in figure 2 may be made in order to simplify the design of an oxygen delivery system. If, however, economy in the use of oxygen is paramount this curve represents the minimum oxygen concentration which is acceptable at a given altitude.

The heavy curve of figure 2 relates to the concentration of oxygen in the inspired gas. This concentration may however, if a mask leak is present, be less than the concentration of oxygen delivered to the mask by the oxygen system. There are several ways in which the presence of an inboard mask leak may be combatted. These include increasing the concentration of oxygen in the gas delivered to the mask, by adding a continuous flow of oxygen to that provided by the demand valve or by maintaining the pressure in the mask cavity during inspiration greater than that of the environment (safety pressure). The maintenance of safety pressure in the mask cavity is the most effective and reliable of these alternatives. In practice it may not be possible to maintain the pressure in the mask greater than that of the environment throughout all inspirations without greatly increasing the mean and maximum mask cavity pressures. Since inboard leakage is proportionally much greater during quiet breathing and becomes insignificant as far as hypoxia is concerned during heavy breathing it is generally adequate to maintain mask cavity pressure greater than that of the environment at inspiratory flows of up to 70 $\ell(ATPD)min^{-1}$. If the oxygen delivery system provides safety pressure at all altitudes then there will be a gross loss of oxygen whenever the mask is not secured to the user's face. This disadvantage can be overcome by either the use of a manual on/off valve in the oxygen supply or only providing safety pressure when it is necessary. Thus, when the system is delivering oxygen diluted with air, inboard mask leakage will not cause significant hypoxia (depending on the degree of air dilution employed) until the cabin altitude exceeds 8,000 to 10,000 feet. In this condition of use safety pressure can be switched into operation above a specified cabin altitude, eg 10,000 feet. When the breathing equipment is being used to prevent inboard

leakage of toxic fumes from the surrounding cabin environment safety pressure should be present at all altitudes. Thus, it should be possible to select safety pressure by a manual operation at any altitude.

Assuming that mask leaks are not present then it is possible using the mean maximum pulmonary ventilations derived for single and two crew combat aircraft (23.0 and 19.7 $\ell(BTPS)min^{-1}$ respectively) and the curves presented in figure 2 to calculate the capacity of the oxygen supply required in a given combat aircraft. The results of these calculations are presented in figure 3. The initial peak in the rate of consumption of the oxygen supply, that at 17,000 feet, is the consequence of the need to prevent hypoxia during and immediately after a rapid decompression at high altitude. The second peak, that at 25,000 feet, is the result of system delivering 100% oxygen at all cabin altitudes above 25,000 feet. With a cabin differential pressure of 5.0 Lb in^{-2}, the cabin altitude will not normally exceed 22,500 feet in an aircraft with a ceiling of 50,000 feet.

IMPEDANCE TO RESPIRATION

The impedance to respiration imposed by current conventional pressure demand oxygen systems is excessive especially when high flows are demanded from the system as during speech (4), air combat (10), and during head movements which change the volume of the inlet hose to the mask (16). The imposition of a high impedance to breathing gives rise to fatigue of the respiratory muscles, discomfort and in some individuals to hypoventilation and in others to hyperventilation. Although ideally the oxygen delivery system should not impose any impedance to respiration this situation cannot be achieved in practice. The practical compromises which should be achieved in an Advanced Oxygen System are outlined in the following paragraphs. The impedance to respiration imposed by a breathing system can be defined by specifying the allowable relationships between pressure in the mask cavity and the corresponding respiratory demands. It is most meaningful to relate minimum and maximum mask pressures during a respiratory cycle to the corresponding peak inspiratory and expiratory flows demanded by the wearer. The pressure at the lips (ie in the mask cavity) meaned over the whole respiratory cycle is also a useful expression of the performance of an oxygen delivery system as this quantity determines, in part, the cardiorespiratory stresses imposed by the equipment.

Respiratory Demands

The respiratory demands placed upon an oxygen delivery system by the aircrewmember can vary widely. The highest instantaneous flows occur during and immediately after heavy work such as air combat and rapid cockpit entry and take off. Peak inspiratory flow is also very high during speech although the pulmonary ventilation may be relatively low (4). The peak inspiratory and expiratory flows of aircrew which must be met by oxygen delivery systems can be as high as 170 $\ell(ATPD)min^{-1}$. The rate of change of respiratory flow also plays a part in determining the dynamic behaviour of oxygen delivery equipment. The rate of change of inspiratory and expiratory flow can be as high as 15 $\ell(ATPD)sec^{2}$.

Mask Cavity Pressures

Mask pressure swing. The total change of pressure in the mask cavity throughout the respiratory cycle (ie the difference between the minimum and maximum mask cavity pressures) should be as low as possible. The greater this total swing the greater is the sensation of resistance to breathing and the greater is the incidence of hyperventilation, particularly in inexperienced aircrew and in situations of high mental workload. The total change of mask cavity pressure during the respiratory cycle during normal use at altitudes up to 50,000 feet with or without safety pressure present should not exceed:

a. 0.5 kPa (2.0 inch water gauge) at peak respiratory flows of 30 $\ell(ATPD)min^{-1}$ and

b. 1.0 kPa (4.0 inch water gauge) at peak respiratory flows of 110 $\ell(ATPD)min^{-1}$.

Minimum mask pressure. The absolute minimum mask pressure during the respiratory cycle should not be lower than a certain level (related to the peak inspiratory flow) otherwise there is a sensation of excessive inspiratory resistance. The minimum mask cavity pressure during inspiration in normal use at all altitudes below 38,000 feet (when safety pressure is not present) should not be lower (in the absolute sense) than:

a. -0.38 kPa (1.5 inch water gauge) at a peak inspiratory flow of 30 $\ell(ATPD)min^{-1}$ and

b. -0.63 kPa (2.5 inch water gauge) at a peak inspiratory flow of 110 $\ell(ATPD)min^{-1}$.

When safety pressure is present the minimum mask cavity pressure is determined by the requirement to maintain the mask pressure greater than that of the environment at inspiratory flows up to at least 70 $\ell(ATPD)min^{-1}$.

Maximum mask pressure. The maximum mask cavity pressure during expiration must not exceed a certain level, related to the expiratory flow otherwise there will be a sensation of excessive resistance to expiration. The maximum mask cavity pressures during expiration in normal use at all altitudes below 38,000 feet (when safety pressure is not present) should not be greater than:

a. 0.38 kPa (1.5 inch water gauge) at a peak expiratory flow of 30 $\ell(ATPD)min^{-1}$, and

b. 0.75 kPa (3.0 inch water gauge) at a peak expiratory flow of 110 $\ell(ATPD)min^{-1}$.

When safety pressure is present the corresponding limits for maximum mask pressure are (a) 0.75 kPa (3.0 inch water gauge) and (b) 1.0 kPa (4.0 inch water gauge).

Allowable further increases in mask pressure. In use, certain routine and emergency conditions tend to raise the pressures in the mask cavity above the values seen during breathing in the steady state. Thus, in a typical pressure demand system in which the outlet valve of the mask is compensated to the pressure in the inlet hose of the mask, head movement increases the pressure in the mask hose and hence the resistance to

expiration and similarly a rise of mask hose pressure produced by a rapid ascent also increases the expiratory resistance. In order to maintain breathing comfort it is highly desirable that the rise of mask cavity induced by realistic head movements or by the maximum rate of ascent of cabin altitude should not exceed 0.125 kPa (0.5 inch water gauge). The rise of mask pressure induced by a failure of the pressure cabin (rapid decompression to an altitude below 50,000 feet) or by a continuous flow failure of the demand valve of the oxygen delivery system should not be such as to over-expand the lungs to the extent that there is a risk of lung damage. Thus the mask pressure in these circumstances (rapid decompression to 50,000 feet in 0.1 sec or a failure giving a full flow of oxygen into the delivery system) should not exceed 5-9 kPa (20-36 inch water gauge).

PRESSURE BREATHING

Prevention of Hypoxia Above 40,000 Feet

Pressure breathing with 100% oxygen is required to prevent serious hypoxia on exposure to altitudes above 40,000 feet. Pressure breathing with a pressure sealing mask is used to provide short duration protection against hypoxia on exposure to pressure altitudes up to 50,000 feet. The mean mask cavity pressure required at 50,000 feet is a compromise between too high a pressure which will produce syncope and too low a pressure which will not prevent a serious deterioration of performance due to hypoxia. The acceptable compromise is a mean mask pressure between 4.0 and 4.5 kPa (16-18 inch water gauge) at 50,000 feet. Between 40,000 feet and 50,000 feet the mean mask pressure should increase linearly with fall of environmental pressure, the limits of mean mask pressure at 40,000 feet being +0.1 to +1.0 kPa (0.4 to 4.0 inch water gauge).

Press-to-Test Facility

A facility whereby pressure breathing may be obtained by the operation of a manual control is required to enable the user to test the standard of seal of the low pressure delivery system up to and including the mask. The performance of this facility is to be such that the user can complete several respiratory cycles with the mask pressure raised. The mean mask pressure produced by the facility should be within the limits 3.5 and 4.5 kPa (14-18 inch water gauge). The total change of mask cavity pressure during the operation of the press-to-test facility should not exceed 0.75 kPa (3.0 inch water gauge) with peak respiratory flows of 30 $\ell(ATPD)min^{-1}$.

Protection Against Sustained Positive Acceleration

Positive pressure breathing can be employed to increase tolerance to sustained positive acceleration. Thus, raising the intrapulmonary pressure by 0.7 kPa (5 mm Hg) per G increases the relaxed G threshold by 0.8-1.0 G. When pressure breathing is used to enhance tolerance of positive acceleration the mean mask cavity pressure should increase linearly with acceleration so that the mean mask pressure is 0.7 x G kPa where G is the total applied acceleration. Pressure breathing should commence with increasing acceleration at between 3.8 and 4.2 G and should cease with decreasing acceleration at between 2.8 and 3.2 G. The total swing of mask cavity pressure during the respiratory cycle when pressure breathing is operative should not exceed 1.0 kPa (4.0 inch water gauge) with peak inspiratory and expiratory flows of 110 $\ell(ATPD)min^{-1}$.

PROTECTION AGAINST CHEMICAL WARFARE AGENTS

When required, an Advanced Oxygen System must be capable of providing adequate protection to the respiratory tract against the effects of chemical warfare (CW) agents in vapour, aerosol or liquid form present both external to the aircraft and within the crew compartment. The system must provide protection to the respiratory tract to a specified protection factor. This protection is provided by the delivery of gas free of significant quantities of CW agents to the respiratory tract and the maintenance of safety pressure in the mask cavity at inspiratory flows of up to at least 85 $\ell(ATPD)min^{-1}$ at all cabin altitudes from ground level to 38,000 feet. The performance of the oxygen system when providing protection against CW agents with respect to the concentration of oxygen in the inspired gas, the impedance which it imposes on respiration and the provision of pressure breathing at high altitude and on exposure to $+G_z$ should meet the requirements specified in the preceding paragraphs. The complete oxygen delivery system must be designed so that CW agents cannot gain access to the gas passing to the respiratory tract. It will probably be necessary to insert a replaceable chemical (activated charcoal) filter in the air supply and perhaps the oxygen supply to the regulator.

Provision of protection against CW agents will almost certainly involve the use of a special to task aircrew NBC respirator which envelops the head and which is divided into two compartments by an internal oronasal mask. The latter will be the means of delivery of the gas from the regulating package to the respiratory tract. The hood compartment of the respirator (that part which is external to the oronasal mask) will also require a supply of gas free of CW agents. A continuous flow of gas through this compartment will provide the required protection against CW agents to the eyes, will prevent misting of the internal surface of the visual area of the compartment and alleviate the thermal strain induced by wearing the respirator. The flow of CW agent free gas required to purge the hood compartment is of the order of 50 $\ell(ATPD)min^{-1}$. In order to minimise the rate of use of oxygen it should be air rather than oxygen enriched air. It is desirable that the provision of this hood compartment air is integrated closely with the provision of gas to the respiratory tract.

OPERATIONAL FEATURES

Duplication of Essential Features

In a low differential pressure cabin the oxygen system is the primary means of protection against hypoxia. Furthermore, in a CW environment the oxygen system as envisaged here provides the primary protection against toxic agents to the respiratory tract (and probably the eyes). It is essential therefore that an Advanced Oxygen System has a very high degree of reliability. Experience has shown that the desired level of reliability can only be obtained by the duplication of certain parts of an oxygen system, specifically the source of breathing gas and the demand regulator.

An Advanced Oxygen System should therefore provide an alternative supply (emergency) of oxygen, albeit of limited duration. A gaseous store containing 70 Litre (NTP) of oxygen will meet this requirement. The user must be able to turn on the emergency supply by manual operation of a simple control. There must be an alternative means of obtaining gas from the main and the emergency oxygen supplies in the event of a failure of the main regulator to pass gas. The need for this facility under CW conditions dictates that the secondary standby regulating device must be a demand valve. When selected, the secondary regulator should also maintain safety pressure in the mask cavity. The need for the secondary regulator to provide pressure breathing on exposure to either cabin altitudes above 40,000 feet or sustained positive accelerations will depend upon the exact role of the aircraft to which the system is to be fitted and the complication involved in providing these facilities.

Warning of System Failure

The user must be given an unequivocal warning of a failure of the oxygen delivery system which could give rise to hypoxia. Apart from warnings incorporated in the Central Warning System of the aircraft the most effective method of indicating a malfunction of an oxygen system is the immediate imposition of a high resistance to inspiration. With an onboard oxygen generation system it is necessary to provide a means of monitoring the partial pressure of oxygen (P_{O_2}) in the gas delivered to the respiratory tract. The output of the P_{O_2} sensor can be used to provide warning of system failure. The P_{O_2} sensor should monitor the P_{O_2} at the outlet of the regulator rather than in the mask cavity (1).

Simplicity of Emergency Drills

The operations which have to be carried out in the event of a failure of a component of some current oxygen systems especially those employing body mounted regulators are complex. The ability of the user to carry out the operations correctly and rapidly may well be impaired by the malfunction of the system. It is essential in an Advanced Oxygen System that the diagnosis of a fault in the system and the steps to be taken to correct it shall be as simple as possible. Ideally it should only be necessary for the user to perform a single operation in order to obtain gas from the emergency supply through the secondary regulator. Furthermore, if the cause of the malfunction or the apparent malfunction is not a failure of the main supply to the regulator then the emergency oxygen supply should remain intact and the user should be able to determine that he is not using it.

Protection Against Hypoxia on Escape

An Advanced Oxygen System should prevent hypoxia during escape at high altitude. Thus it should automatically provide oxygen following ejection at high altitude down to the altitude at which the man separates from the ejection seat during the escape sequence (below 18,000 feet). The oxygen supply required for this protection can be the emergency supply (70 ℓ(NTP)) necessary to meet the requirements for an alternative secondary supply of oxygen. Ejection of the seat and user from the aircraft should turn on the supply.

Antidrowning and Antisuffocation Facilities

An Advanced Oxygen System should prevent water being drawn into the mask cavity when the crewmember is immersed in water up to the level of his neck and provide a means in these circumstances of inspiring air through a valve at head level. Thus the system should be fitted with self-sealing valves to prevent water being drawn into the oronasal mask on immersion of the body below the neck in water. These valves shall come into operation automatically during the escape sequence at man-seat separation. The oronasal mask should be fitted with an inward relief valve which allows air to be drawn in during inspiration only when the oxygen mask hose is separated from the oxygen supply system during the escape sequence. A simple spring loaded inward relief valve which opens at a mask suction of 1.25-1.75 kPa (5-7 inch water gauge) will suffice for this purpose. Such a simple antisuffocation valve will not be acceptable, however, when an aircrew NBC respirator is used. An alternative method of obtaining inwards relief or deletion of the antidrowning facility when this equipment is worn is required.

SOURCE OF ROUTINE OXYGEN SUPPLY IN FLIGHT

A. CURRENT SYSTEMS

Liquid Oxygen Storage Systems

Virtually all current combat aircraft carry oxygen in liquid form (LOX). The LOX is produced from air by ground based plant and transported in large vacuum flasks to smaller flasks from which the aircraft LOX converters are charged either in situ in the aircraft or out of the aircraft in servicing bays. In general, modern LOX converters currently fitted to many aircraft reliably supply oxygen at between 70 and 300 Lb in^{-2} to the oxygen regulators. The logistics of manufacture and transport of LOX to the aircraft LOX converter are, however, considerable. Only a small proportion (less than 20%) of the LOX generated in the manufacturing plant reaches the aircraft LOX converter owing to the need to evaporate LOX to cool the containers and maintain the remainder of the oxygen in the liquid form. Even when the converter is filled, oxygen is subsequently lost as gas as heat leaks into the liquid within the container. Furthermore, whenever LOX is handled there is an increased fire hazard and considerable care has to be exercised to avoid contamination of LOX with hydrocarbons, halogen compounds and other substances which can reach toxic levels in the oxygen supplied by the LOX converter to the breathing system. Finally, with the need to ensure that the LOX converter will supply gaseous oxygen at the required pressure soon after refilling with LOX in spite of agitation of the contents of the converter by aircraft manoeuvres, the control systems of LOX converters have become complicated requiring additional maintenance. Thus for these reasons and the operational considerations discussed earlier in this paper, provision of oxygen required for breathing by a LOX storage system which is recharged from a container on the ground is not the method of choice for use in future combat aircraft.

Gaseous Oxygen Storage Systems

Oxygen is carried in a few combat aircraft as compressed gas. The low pressure storage system (450 Lb in^{-2}) which was widely used in US combat aircraft during and immediately after World War II is no longer employed. Certain UK combat aircraft employ the high pressure (1800 Lb in^{-2}) oxygen storage system which was developed in World War II. The hazard to the aircraft and its occupants from a burst storage cylinder is minimised by employing wire would steel cylinders. The disadvantage of this type of system is the need for large and heavy oxygen charging facilities operating at 3,600 Lb in^{-2} and the relatively high installed weight of the system (some 2.0 to 2.5 times that of a LOX converter storing the same quantity of oxygen). Recently, interest in the use of oxygen storage vessels charged to 5,000 Lb in^{-2} has arisen in the UK. Initial vulnerability tests of available spherical vessels have suggested that such a storage system can be regarded as safe. The installed weight of a 5,000 Lb in^{-2} storage system is similar to that of a LOX converter system storing a similar quantity of oxygen. Although this approach may be of value in special circumstances, eg Sea Harriers operating from "Through Deck Carriers", it has the great disadvantage that the aircraft store requires recharging and that a source of oxygen at very high pressure is required for this purpose on the ground.

B. ON BOARD GENERATION OF OXYGEN

General

The most attractive method of obtaining the oxygen required for the aircrew of a combat aircraft in flight is to manufacture the gas on board the aircraft. Generation of the oxygen required on board the aircraft eliminates the logistic and operational turn round problems associated with the use of storage systems which have to be replenished whilst the aircraft is on the ground. The last 10 years has seen the design, development and test of several different methods of onboard generation of oxygen. Much of this work has been carried out in the United States for the US Navy and Air Force. The experience gained of the relative merits of various proposed systems is now such that it is possible to decide which system should be used in future combat aircraft.

The main features of the five methods of onboard generation of oxygen which have been proposed and developed primarily in the United States are summarised below. The design requirement set for most of these systems was the production of 100% oxygen at a maximum flow of 26 ℓ(NTP) per min at ground level so that the generating system could be used to supply oxygen to a two-man crew through conventional diluter demand oxygen regulators. The pressure at which the oxygen was produced to the generating system was to be high (900-1800 Lb in^{-2}) and where necessary the system was to include a compressor to produce this pressure. The generating system was also to include an accumulator which would store about 300 ℓ(NTP) of oxygen.

(i) Water electrolysis system. NASA Ames sponsored the development of a water electrolysis system for the generation of oxygen in flight. The electrical power requirements of this system are, however, relatively very high. Furthermore, this system requires replenishing on the ground with water of a very high standard of chemical purity if the output of the cells is not to deteriorate. Development of this system has been abandoned in the US.

(ii) Barium oxide/dioxide system. Barium oxide when heated to 540°C will react with molecular oxygen to form barium dioxide. If the temperature of the barium dioxide is raised to 900°C it breaks down giving off molecular oxygen (equation 1).

$$2\ BaO + O_2 \underset{900^{\circ}C}{\overset{540^{\circ}C}{\rightleftharpoons}} 2\ Ba\ O_2\ . \qquad \text{(equation 1)}$$

The Brin process is a development of this reaction employing a specially prepared barium oxide/dioxide mixture. The compound is held at a constant temperature of 760°C when it will extract oxygen from air at raised pressure and release the oxygen when the pressure is reduced. With an appropriate preparation of the compound this process can be repeated in a cyclic manner with no loss of absorptive capacity. The onboard generation system consists of two parallel beds of heated barium oxide/dioxide which are alternately pressurised with engine bleed air at 70 Lb in^{-2} gauge. Oxygen is extracted from each bed in turn by a compressor which reduces the pressure in the bed to 2.0 Lb in^{-2} absolute, raises the pressure of the oxygen to 1800 Lb in^{-2} and feeds it to a reservoir. In order to maintain the efficiency of the barium oxide/dioxide beds the air fed to them must be free of carbon dioxide, water vapour and oil. Appropriate molecular sieves and filters are fitted upstream of the beds. Electrical power is required to produce and maintain the high temperature in the beds and to operate the oxygen compressor and valve sequencing equipment. The major characteristics of a typical barium oxide/dioxide onboard oxygen generator are given in Table 1. Development of this system was carried out by The Bendix Corporation. The complexity of the system, its high power consumption and need for frequent maintenance has led to the abandonment of this approach.

(iii) Electrochemical Concentrator. This operates on an ion exchange principle. Oxygen is "pumped" electrochemically using electrical power from an air stream through a sulphonated solid polymer electrolyte. Oxygen molecules from the air are combined at the cathode with hydrogen ions contained in the electrolyte to form water molecules (equation 2).

$$O_2 + 4H^+ + 4e^- \rightarrow 2\ H_2O\ . \qquad \text{(equation 2)}$$

The water molecules migrate through the electrolyte to the anode where they are electrolysed (equation 3), the oxygen being evolved as a pure gas and the hydrogen ions returning to the electrolyte.

$$2H_2O \rightarrow 4H^+ + 4e^- + O_2\ . \qquad \text{(equation 3)}$$

Table 1. Summary of Major Characteristics of Typical Onboard Oxygen Generating Systems

	Barium Oxide	Electromechanical Concentrator	Fluomine	Molecular Sieve
Oxygen production (ℓ(NTP)min^{-1})	26	26	26	26
Oxygen storage (ℓ(NTP))	225	260	320	2-4
Weight (kg)	43	37	52	14
Volume (ℓ)	70	80	80	40
Air supply				
Pressure (Lb in^{-2})	85	25-80	25-80	120
Temperature (^{o}C)	40	40-200	2-25	5-40
Flow (ℓ(NTP)min^{-1})	260	600	260	190
Coolant fluid				
Temperature (^{o}C)		25	25-50	
Flow (lb hr^{-1})	NONE	1300	800	NONE
Heat load (BTU.hr^{-1})		28,000	13,000	
Heating air				
Temperature (^{o}C)	NONE	NONE	200	NONE
Flow (ℓ(NTP)min^{-1})			0-2000	
Electrical power				
AC (400 Hz) (kW)	3.3	6.4	1.0	-
DC (28V) (kW)	-	-	0.1	0.1

Although there is no nett consumption of water the efficiency of the solid polymer electrolyte cells is greatest when both the air and oxygen sides of the membrane are saturated with water. A typical electrochemical cell stack consists of one hundred 10 inch diameter cells. Engine bleed air is heated and is passed through the stack. The concentrator is capable of generating oxygen at high pressure and a typical maximum oxygen operating pressure is 400 Lb in^{-2}. Water is recovered from the oxygen by cooling the gas in a heat exchanger fed by the aircraft coolant system. The oxygen then passes into an accumulator. The rate of production of oxygen by the concentrator is controlled by switching the electrical power to the cell stack. During start up of the system, electrical heaters raise the temperature of the bleed air entering the stack to about 100^{o}C. A fully developed electrochemical concentrator was developed by the General Electric Company for the United States Navy. Its major characteristics are summarised in Table 1. The system has recently been evaluated by NADC when its performance was found to be unsatisfactory. Further development, test and evaluation of this form of onboard generation system has been discontinued.

(iv) Fluomine system. This system employs the reversible reaction of oxygen with the cobalt chelate, fluomine. This substance forms a coordination complex with molecular oxygen. Engine bleed air at a pressure of 25 Lb in^{-2} is passed through a bed of fluomine and oxygen is taken up by the fluomine. After a predetermined time the bleed air is turned off, the fluomine bed is heated to about 110^{o}C by directing hot coolant and hot air through the fins with which the fluomine is in intimate contact, and the pressure in the bed reduced to about 7 Lb in^{-2}. The initial volume of air from the bed is discarded and then the oxygen liberated from the fluomine by heating and reduction of pressure is drawn into a compressor which raises the pressure of the oxygen to 120 Lb in^{-2} for supply directly to the demand regulator and to 1300 Lb in^{-2} for storage in a reservoir. The system employs two beds of fluomine arranged in parallel so that whilst one is in the absorption phase the other is in the desorption phase. A control system switches automatically the bled air inflow and outflow, the connection to the inlet to the compressor and the flow of heating and cooling fluids through the fins of the fluomine beds from one bed to another. The major characteristics of this fluomine system are summarised in Table 1. Considerable difficulty has been experienced in manufacturing fluomine which maintains its capacity for absorbing oxygen. Indeed, recent tests by the USN and USAF of the developed system produced by the Air Research Manufacturing Company have led to the conclusion that the performance of the developed fluomine system is not fully satisfactory.

(v) Molecular Sieve System. The use of a molecular sieve to concentrate the oxygen present in air by the selective absorption of nitrogen has been used for many years in ground based oxygen generation plants. Consideration of its use as an onboard oxygen generation system was delayed by the inability of the systems originally proposed to produce 100% oxygen. Recently, however, molecular sieve systems

suitable for use in flight which deliver 95% oxygen have been developed. These systems use 5A molecular sieve (a zeolite, which is a crystalline aluminosilicate compound) to adsorb nitrogen from the air. The molecular sieve has highly uniform pores with dimensions in the molecular range. The dimensions of the pores of 5A molecular sieve are such that they selectively adsorb nitrogen from air so that an oxygen-argon rich mixture remains. The retained molecules are held by Van der Waals forces and can be released from the sieve by reduction of pressure and a rise of temperature. The molecular sieve oxygen generating system employs two parallel beds of 5A molecular sieve through which engine bleed air at a pressure of 60 Lb in^{-2} is passed alternately. As the air flows through the bed (which contains 5 kg of molecular sieve in the '2 man' system) the nitrogen is passively removed so that the gas leaving the bed consists of 95% oxygen and 5% argon. After an appropriate time the air flow is switched off and the pressure in the bed is reduced by venting it to ambient so that the nitrogen held in the molecular sieve is desorbed. This desorption process is aided by passing a fraction of the oxygen/argon mixture being produced by the other bed through the desorption bed. The oxygen/argon mixture flowing from the beds passes into a 1ℓ capacity plenum chamber and thence to the demand regulator. The major characteristics of the molecular sieve system are summarised in Table I. If the pressure at which air is delivered to the molecular sieve is too low or the flow of gas demand from the system is too high then the removal of nitrogen by the molecular sieve as the air flows through the bed is incomplete. Thus at low inlet pressures and high demanded flows this system yields oxygen-argon diluted with nitrogen. Indeed, in the early systems developed for airborne use the delivered gas contained only 50 to 70% oxygen at ground level, although this concentration increased with ascent to altitude. However, improvements in the design of the beds and changes in the cycle times have resulted in systems which at low and moderate demands (20-26ℓ(ATP) min^{-1}) yield 95% oxygen and 5% argon, when the inlet pressure to bed is above 40 Lb in^{-2} (12). The 5% of argon which is present in the gas delivered by the system is considered very unlikely to increase the risk of decompression sickness arising on exposure to high altitude. Molecular sieve onboard oxygen generation systems have the great advantages that they are relatively simple, they are highly reliable and have a very low power consumption. The disadvantages of the generators developed so far are: that they require a supply of air at a pressure greater than 40-50 Lb in^{-2} if the oxygen produced is not to be diluted with nitrogen; that nitrogen will be present in the gas delivered by the system if excess flows are demanded from it; and that the pressure at which gas is delivered by the system is always less than 60 Lb in^{-2} and that this varies directly with the pressure at which gas is delivered to it (below the 60 Lb in^{-2} pressure employed in the molecular sieve beds). Thus either a compressor is required to raise the pressure of the oxygen to an acceptable level or a demand valve operating at a low inlet pressure must be used. The satisfactory performance and reliability of molecular sieve onboard generation systems (manufactured primarily by The Bendix Corporation) has been demonstrated by extensive laboratory (12,17) and flight trials (15).

Choice of Onboard Oxygen Generation System

The simplest and most reliable form of onboard oxygen generating system under development is believed to be the molecular sieve. This system also has the advantages that it requires a minimum of electrical power and no special cooling or heating and is relatively light and compact (Table 1). The form of breathing gas regulation system proposed in this paper will overcome in part the disadvantages that the molecular sieve will, under certain conditions, deliver gas containing some nitrogen and the adverse effect of low inlet pressures on the performance of the sieve. The molecular sieve system is considered to be the system of choice for use in an Advanced Oxygen System for future combat aircraft. The reduction of performance of the molecular sieve at very low pressures makes it highly desirable that at least for certain parts of the flight envelope the pressure at which air is delivered to the sieve is raised by a special-to-task compressor. This compressor may be fed directly with engine bleed air or with air from the pressure cabin. The addition of this compressor, which should probably be driven by an electric motor, will also provide the compressed air required for the pressure premix unit. It will in addition permit the oxygen system to be used on the ground when the aircraft engine is not running by the use of external electrical supplies.

SECONDARY (EMERGENCY) OXYGEN SUPPLY

A secondary supply of oxygen is required as a source of breathing gas in the event of a failure of routine (main) supply and in the event of escape at high altitude. In present combat aircraft the secondary oxygen supply is stored as gas at high pressure (1800 Lb in^{-2}). Over the last 10 years or so the use of sodium chlorate/iron candles ("solid oxygen") has been considered as a secondary source of oxygen in combat aircraft. Although the logistics and maintenance aspects of chlorate candles are very attractive a complex form (consisting of a series of small discrete units) is required to permit the supply to be turned off before it is exhausted and to supply a fluctuating flow of oxygen as occurs with a demand regulating system. It is concluded that the secondary (emergency) supply in an Advanced Oxygen System should be held as oxygen gas at 1800 Lb in^{-2}. The pressure of the oxygen in the store (ie contents) should be presented at a site where it can be seen in flight by the user. The preferential use of the main oxygen source when the secondary source is turned on can be ensured by reducing the pressure at which the secondary oxygen is supplied to the regulating package, to a value significantly less than that at which the main supply is delivered, eg main supply at 70-85 Lb in^{-2}, and secondary supply at 45-50 Lb in^{-2}. The secondary source should have a capacity of 70-100 ℓ(NTP).

REGULATING PACKAGE

General

The flow of gas from the oxygen supply and admixture with air are controlled by a regulating package, the outlet of which is connected by flexible hose to the inlet port of the aircrew oronasal mask (or aircrew NBC respirator) (figure 4). The wide experience of the Royal Air Force with respect to various sites for mounting demand regulators has led to the conclusion that in combat aircraft the regulating package should be mounted on the structure of the ejection seat. The most suitable site is the side of the seat pan where it is easy to locate controls and inlet and outlet pipes and connectors can be routed between the side of the seat and the side console of the cockpit. The regulating package and the associated connectors for inlet and outlet hoses should be mounted on a single easily detachable plate so that the package and connector unit can be removed

from and replaced on the seat as a single unit. The secondary oxygen supply should also be mounted on the ejection seat. It is connected to the regulating package by a flexible hose and a quick release locking connector.

Duplication of Demand Regulators

In view of the essential service provided by the oxygen system and the complexity of a demand regulator which is required to provide all the facilities discussed earlier in this paper there must be an alternative regulating system which can be used in the event of failure of the main (primary) regulator. Since a continuous flow standby (secondary) system is wasteful of oxygen and the protection which it provides against hypoxia is substandard it is concluded that the alternative regulating system (standby or secondary regulator) should consist of a second demand regulator. The gas supply (routine (main) and secondary) to the demand regulators would pass through a manually operated selector valve which switches the supply to either the main or the standby regulator (figure 4). The outlets of the two regulators would pass into a common chamber and thence by way of a connector to the hose to the mask.

Dilution of Oxygen with Air

In order to achieve economy of the use of oxygen (either from a LOX store or from a molecular sieve onboard oxygen generator) the gas from the routine oxygen supply system is diluted with air in the regulating package.

In current pressure demand regulators the oxygen, after passing through the demand valve, is diluted with air by creating a depression downstream of the demand valve by means of an injector mechanism. This method of diluting oxygen with air is unsatisfactory since the degree of dilution varies with the flow of gas through the regulator and from one regulator to another. Furthermore, an injector will not dilute the oxygen when the gas delivery pressure is raised to provide pressure breathing. Thus, the conventional injector diluting mechanism cannot be used to provide the close control of the concentration of oxygen in the inspired gas necessary to give the best economy of the use of the aircraft oxygen supply. Furthermore, it cannot be used to provide dilution during pressure breathing on exposure to $+G_z$.

The most satisfactory method of obtaining the desired close control of dilution of oxygen with air, both with cabin altitude and during pressure breathing at low altitude is to mix oxygen and air in the desired proportions at high pressure upstream of the demand valve of the regulator (figure 4). This technique of pressure premix which was proposed by Roxburgh in 1959 is relatively simple and several prototype systems have already been built. The mixing of the high pressure oxygen and air is controlled in relation to cabin altitude to be as close as possible to the dilution required to maintain an inspired (tracheal) P_{O_2} of 122-130 mm Hg at cabin altitudes up to about 22,500 feet. Above this altitude the premix unit provides 100% oxygen. The degree of dilution at a given cabin altitude is independent of the flow of gas through the pressure premix unit. When required, 100% oxygen can be selected in flight by turning off the supply of air to the premix unit. The premix unit is designed so that in the event of a cessation of the oxygen supply it fails to pass any gas thus ensuring that the user is warned of a potentially hypoxic situation. The use of pressure premix allows simplification of the main and secondary regulators which no longer have to incorporate an injector mechanism. The volume of the pipework between the mixing point in the pressure premix unit and the regulator package must be kept low in order to ensure the delivery of 100% oxygen immediately it is required, eg on a rapid decompression. Indeed, it is considered that the pressure premix unit should be mounted alongside, if not mounted in, the regulator package.

Under certain operating conditions the molecular sieve onboard oxygen generating system may deliver gas which contains a proportion of nitrogen. The proportioning of the flow of gas from the molecular sieve and of compressed air to the demand regulator by the premix unit will therefore be controlled in an Advanced Oxygen System by a sensor which monitors the P_{O_2} in the gas flowing from the regulator (figure 4). With such a servo control system and an absolute cabin pressure transducer it is possible to maintain the desired P_{O_2} in the gas delivered by the demand regulator at all altitudes and under all flow demands and to ensure that the system provides at least 95% oxygen on decompression of the pressure cabin at high altitude. Reliable fluidic P_{O_2} sensors of the type originally proposed by Stubbs (14) which give a relatively large output are now available. This form of P_{O_2} sensor has already been used experimentally to drive a fluidically controlled premix unit. The P_{O_2} control system could also ensure that the premix unit ceased to provide any gas in the event that the P_{O_2} at the outlet of the regulator fell below an acceptable level (120 mm Hg). The user would then select the secondary (emergency) oxygen supply. A manual control in the control system allows the user to select a high concentration (generally 95%) of oxygen. The output of a second P_{O_2} sensor at the outlet of the regulator operates a warning in the Central Warning System in the event that the P_{O_2} of the gas delivered by the regulator falls below an acceptable level (125 mm Hg).

The only potential disadvantage of pressure premix is the requirement for a supply of compressed air. The mean flow of air required is however relatively small (maximum of the order of 50ℓ(ATPD)min^{-1}). A considerably higher flow of compressed air is required to supply the molecular sieve (eg 200ℓ(NTP)min^{-1} at 25 - 100 Lb in^{-2}). Thus the compressor which it is proposed should be fitted to supply air to the molecular sieve onboard oxygen generation system under conditions in which the pressure at which air is delivered from the aircraft engine is too low or the engine is not operating can also supply air to the premix unit. If considerations of the weight, size and power of the compressor allow, then it is highly desirable that it delivers air at 50-60 Lb in^{-2} to the molecular sieve and the premix unit. It would, however, be possible to employ a compressor which provides air at a lower pressure eg 25 Lb in^{-2}. This would, however, entail the use of demand regulators which operated effectively at inlet pressures of the order of 15-20 Lb in^{-2}.

Demand Regulators

The demand regulators in the regulator package will control the flow of the oxygen-air mixture from the premix unit and of 100% oxygen from the secondary (emergency) supply to the hose to the oronasal mask (or aircrew NBC respirator).

Various different distributions of facilities between the main and standby regulators may be envisaged in a system employing pressure premix. At a minimum, the main regulator will provide gas on demand with safety pressure up to 38,000 feet and pressure breathing above 38,000 feet and on exposure to positive accelerations greater than 3-4G. There is a considerable routine advantage if the safety pressure is supplied automatically at cabin altitudes above 8,000-10,000 feet where it is required to prevent hypoxia due to inboard leakage of air associated with an ill-fitting mask. Thus, if suction is required to induce a flow of gas through the regulator at low cabin altitudes the user can lower his mask without wasting gas. Safety pressure is, however, required under CW conditions at all altitudes from ground level to 38,000 feet. Thus it must be possible to select gas with safety pressure from the main regulator at ground level and all altitudes up to 38,000 feet by means of a manual control. This safety pressure should be greater than that provided automatically at altitudes above 8,000-10,000 feet. The higher safety pressure could be sufficient to ensure that the pressure in the mask cavity of the aircrew respirator is greater than that of the environment at all inspiratory flows.

The design of the standby (secondary) regulator can be somewhat less complex than the main regulator. At the simplest, it could provide gas with safety pressure from ground level, but without pressure breathing on exposure to either altitudes above 38,000 feet or positive acceleration. Such simplification would, however, result in a considerable loss of flexibility and further duplication of facilities is considered highly desirable. Indeed, it is considered that the standby regulator should provide safety pressure from ground level to 38,000 feet, and pressure breathing at altitudes above 38,000 feet and on exposure to positive accelerations. The safety pressure provided by the standby regulator must be adequate to provide the protection required in a CW environment.

A compensated dump valve should be fitted at the common outlet of the regulators to ensure that head movement, rapid ascent, rapid decompression and a continuous flow failure of a regulator do not cause excessive resistance to expiration. Whilst it is possible to provide this facility solely when the main regulator is used it is considered that the compensated dump valve should be in operation whichever regulator is in use. The press-to-test facility whereby regulator delivery pressure can be raised in order to check the performance of the mask valve system and for the absence of leakage at the mask seal and connectors need only be provided on the main regulator.

The performance with respect to impedance to respiration, safety pressure and pressure breathing of both the main and standby regulators should conform in general with the physiological requirements proposed earlier in this paper. These requirements can probably best be met by the use of either a balanced servo operated demand regulator of the type which has been used widely in the US and UK or by a fluidic controlled demand valve. Versions of both these types of regulators which operate at low inlet pressures are at advanced stages of development both in the UK and the US.

Emergency Control

The supplies of oxygen to the regulating package and the demand regulators within the package are both duplicated. It is important whilst maintaining flexibility to ensure that the user has only to perform simple operations in order to make correct and full use of this duplication of supplies and regulators. In order to meet this requirement only one emergency control is fitted. Operation of this emergency control turns on the secondary (emergency) oxygen supply and moves the regulator selector lever so that the premix unit and the secondary supplies are both delivered to the standby regulator (figure 4). It also turns off the compressed air supply to the premix unit in order to ensure that 100% oxygen is supplied on selection of emergency oxygen. This arrangement provides the user, by a simple operation, with an alternative source of oxygen through the standby regulator. If the main supply of breathing gas from the premix unit is intact then the secondary oxygen supply will be unused. (The pressure at which the secondary oxygen supply is delivered is lower than that at which the routine use oxygen is normally supplied.) The pilot can determine whether he is using the secondary (emergency) supply by means of the gauge displaying the contents fitted to the ejection seat. The flexibility of the system is increased by making it possible for the user, having operated the emergency oxygen control, to reselect the main regulator. Rather than allowing direct operation of the regulator selector lever this facility will probably be provided by returning the emergency oxygen control to its original position (although this operation will not turn off the emergency oxygen supply whilst in flight).

Indicators and Warning System

The indicators and warning devices fitted to the system should include a gauge to indicate the pressure at which gas is delivered by the molecular sieve to the premix unit and a flow sensor in the main oxygen supply to the unit. The output of the second P_{O_2} sensor at the outlet of the regulator package should be fed to the Central Warning System. Some serious failures of the system eg a complete failure of main supply or of the demand valve to open will be immediately apparent as a high resistance to inspiration.

MASK ASSEMBLY

The pressure demand oronasal mask used in non CW conditions is to be fitted with a conventional inlet and compensated outlet system. It should possess a reflected edge seal similar to that of the present RAF type P/Q masks. It is highly desirable that the tension of the mask on the face should increase automatically whenever the regulator delivers pressure breathing. A very attractive method of providing this facility is to fit a bladder which is connected to the inlet hose of the mask between the back of the head and the internal harness of the protective helmet. It should also be possible to increase mechanically the pressure of the mask seal on the face by the operation of a manual control.

The connections between the outlet of the regulator package and the mask should be locked in flight and undone automatically during the ejection sequence. Ingress of water subsequent to escape from the aircraft is to be prevented by a self-sealing valve in the oxygen port of the 'man' portion of the PEC. An anti-suffocation valve must be fitted in the mask in order to allow the wearer to breathe after separation from the seat in the ejection sequence. The anti-suffocation valve should not open until a suction of the order of 1.25-1.75 kPa (5-7 inch water gauge) is created in the mask cavity. Special arrangements are required when an aircrew NBC respirator is used with the supply system.

PROTECTION AGAINST CW AGENTS

The gas provided to the regulating package by the routine and secondary supply systems must be free of chemical warfare (CW) agents. It will be possible to charge the secondary supply store with clean oxygen from a suitable ground high pressure source without contaminating this oxygen. The air supplied to the molecular sieve and to the premix unit will, however, in a CW environment be contaminated with toxic agents. These must be removed by activated charcoal filters. In order to reduce the flow of gas which must be filtered by the NBC canister to that which is drawn into the mask it is highly desirable that the filtration canister(s) should be placed downstream of the molecular sieve. It is assumed that CW agents will have no deleterious effect on the performance of the molecular sieve. There are several alternative sites for the filter canisters. A single NBC canister could be placed at the outlet of the premix unit. The disadvantage of this arrangement is that it would greatly increase the bulk of the regulating package and would introduce an undesirable additional capacity between the premix unit and the demand regulators which would delay the delivery of a high concentration of oxygen on a sudden reduction of cabin pressure. A single NBC canister could be placed at the outlet of the demand regulators. The disadvantage of this arrangement is that again it would add considerably to the size of the regulating package and that it would impose a very significant resistance to flow, and thus increase the impedance to respiration. The most attractive solution is to place separate NBC canisters in the oxygen and air supplies to the premix unit. Both of these canisters can be mounted at convenient sites on the airframe rather than on the ejection seat. The resistance to flow through the canister will have no effect upon the performance of the system.

The outlet of the regulating package would be connected through butyl hose and appropriate connectors to the inlet of the oronasal mask of the aircrew NBC respirator. The supply of filtered air required to ventilate the eye space of the aircrew respirator would be obtained from the compressed air supply to the premix unit, downstream of the NBC filter in this supply.

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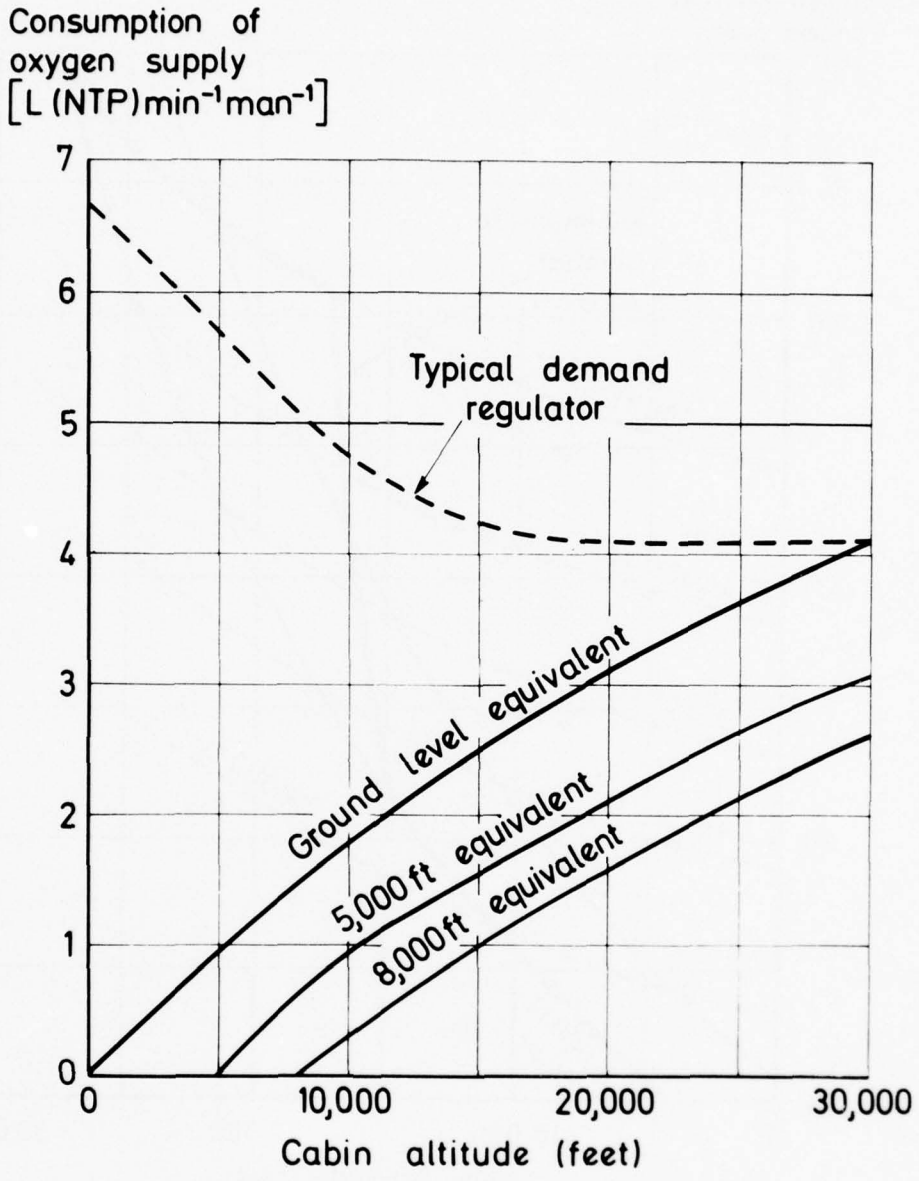


Figure 1. The relationship between the rate of consumption of the oxygen supply and cabin altitude for a conventional demand regulator with injector dilution and for oxygen systems which maintain alveolar oxygen tensions equal to those produced by breathing air at ground level, at 5,000 feet and at 8,000 feet.

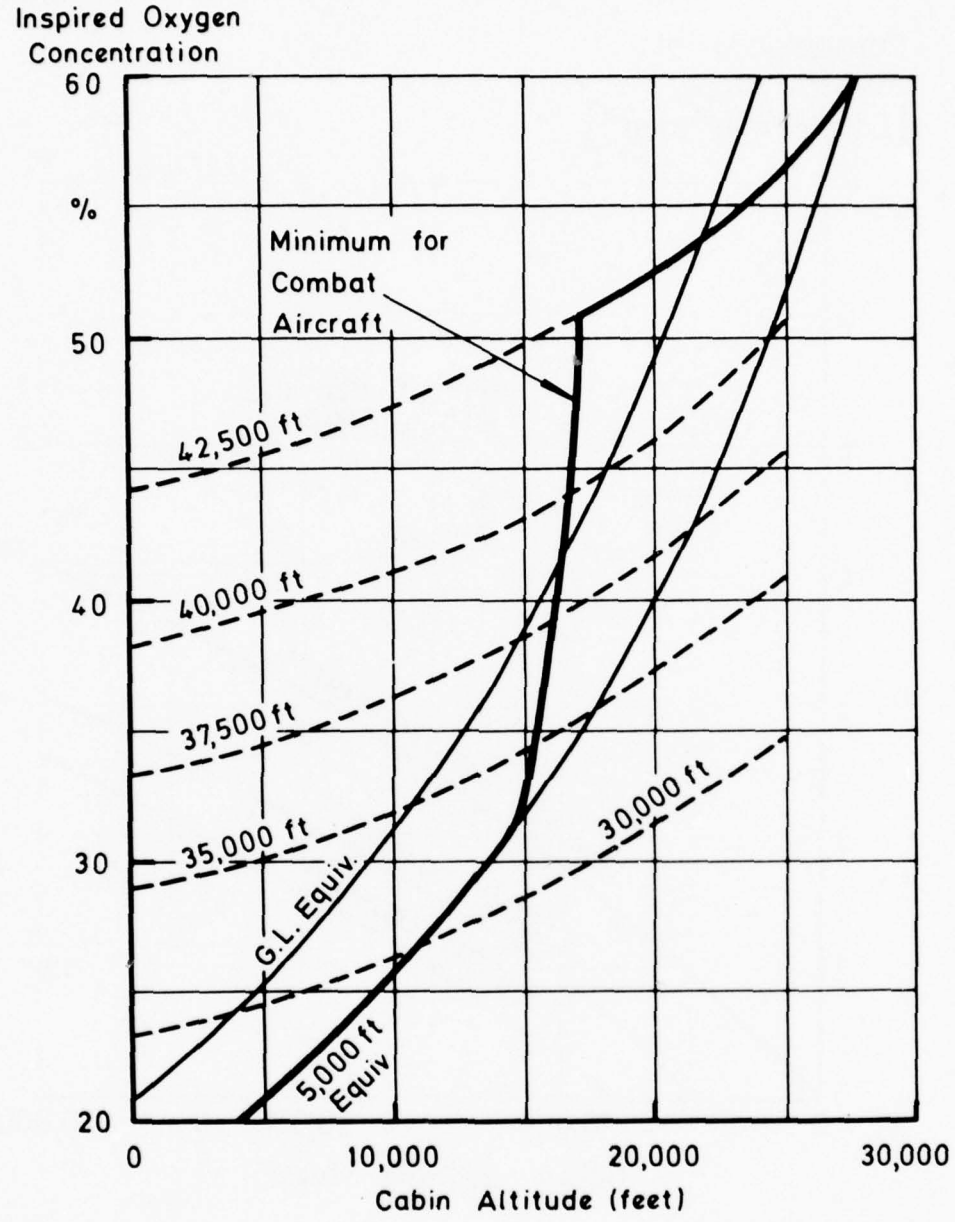


Figure 2. The relationships between the concentration of oxygen in the inspired gas and cabin altitude required (i) to maintain the alveolar oxygen tension equal to that when breathing air at ground level (G.L. Equiv), (ii) to maintain the alveolar oxygen tension equal to that when breathing air at 5,000 feet (5,000 ft Equiv), (iii) to produce an alveolar oxygen tension of 30 mm Hg on instantaneous decompression from the cabin altitude on the 'X' axis to the cabin altitude indicated by the broken horizontal line (final cabin altitudes between 30,000 and 42,500 feet) and (iv) to maintain when the pressure cabin intact the alveolar tension equal to that when breathing air at 5,000 feet and to prevent the alveolar oxygen tension falling to below 30 mm Hg on the instantaneous decompression of a cabin pressurised to a differential pressure of 5 Lb in^{-2} (thick solid line labelled Minimum for Combat Aircraft).

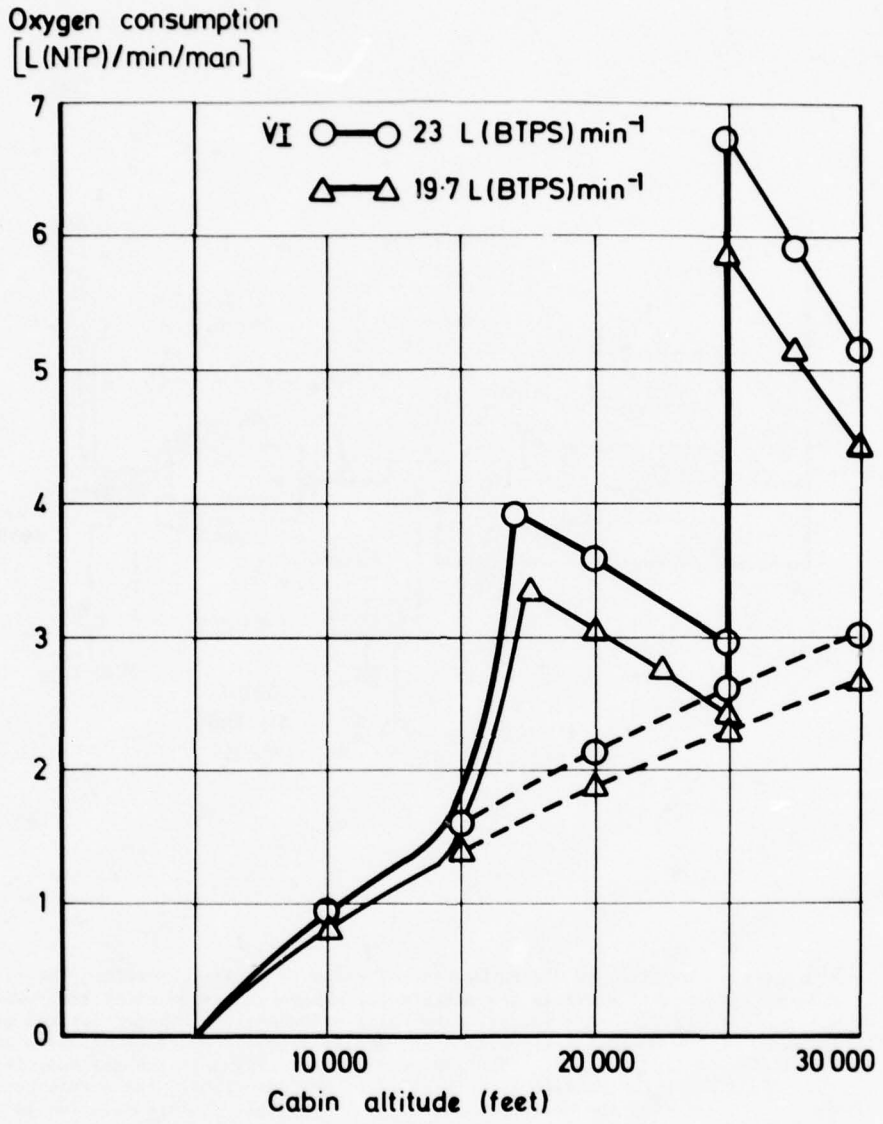


Figure 3. The relationship between the rate of consumption of the oxygen supply and cabin altitude for an oxygen system which meets the relationship between inspired oxygen concentration and altitude derived in this paper. This relationship is shown for two levels of pulmonary ventilation, representing the mean maximum values of pulmonary ventilation for a single and a two-man crew (23 ℓ(BTPS)min^{-1} and 19.7 ℓ(BTPS)min^{-1} respectively).

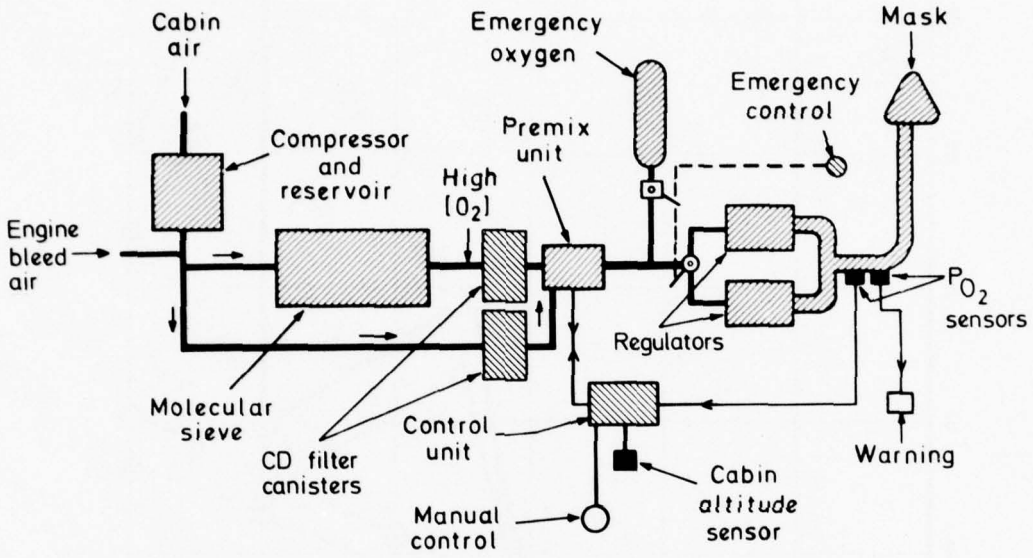


Figure 4. A diagram of an Advanced Oxygen System for a future combat aircraft. The system employs a molecular sieve to concentrate the oxygen in engine bleed air. When the pressure at which air is delivered falls below the minimum for optimal performance of the molecular sieve an electrically driven compressor delivers cabin air at the desired pressure. The concentration of oxygen in the gas supplied to the demand regulator package is controlled by the addition in the premix unit of air to the gas from the molecular sieve. The magnitude of this dilution is determined by a control unit, the inputs to which include cabin altitude and the partial pressure of oxygen in the gas delivered by the regulator package. The gas mixture produced by the premix unit flows to the oronasal mask through the main (primary) demand regulator. In the event of malfunction of the main regulator the secondary standby regulator can be used. An emergency (standby) supply (gaseous oxygen at 1800 Lb in^{-2}) is fitted. Operation of the Emergency control switches on the emergency supply and switches the main/emergency gas supplies to the standby (secondary) regulator. A second P_{O_2} sensor at the outlet of the regulator package provides a warning in the event that the P_{O_2} of the gas delivered by the system falls to below 125 mm Hg.

DISCUSSION

K. Klein — How great is the risk of developing atalectasis during pressure breathing? I wonder if you mix oxygen and air to prevent the development of atelectasis?

J. Ernsting — Yes, that is one of the reasons we have gone to a pre-mixed system.

R. Murray — Would you say a word about oxygen toxicity associated with long duration flight using high concentrations of oxygen?

J. Ernsting — We believe that high concentrations of oxygen, 100% oxygen certainly, are unacceptable in non-combat aircraft and transports if the period of exposure is greater than six hours. In combat aircraft we think 100% oxygen is completely unacceptable for any use and the data we originally presented, and with which most laboratories agree, suggests that you need a minimum of 40% nitrogen in the inspired gas to avoid atalectasis. To avoid lung irritation problems at 1 atmosphere, one should not exceed between 60 and 75% oxygen.

K. Klein — In our deep diving research we are developing decompression tables. We use oxygen up to 2.6 atmospheres for 10 minutes, so, in fact, you can get quite high concentrations of oxygen if you are careful about the safety limits.

J. Ernsting — I think we all use 100% oxygen up to at least 2 atmospheres or even occasionally up to almost 3 atmospheres for treatment of altitude decompression sickness.

THE EUROPEAN APPROACH TO THE SELECTION AND TRAINING OF SL PAYLOAD SPECIALISTS

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SUMMARY

The completed selection of European PS for SL-1 is described. Future developments in European selection programs are projected. The immediate training requirements for the SL-1 PS are described. The integration of such varied training categories as biomedical and physical with the more general SL experiment training is reviewed. The usefulness of mission simulations is also discussed.

The international cooperation in the Shuttle/Spacelab Program offers European scientists an opportunity to participate in space flights as a member of the Spacelab payload crew. The present NASA-ESA Agreement foresees one European Payload Specialist (PS) aboard Spacelab 1 (SL-1). Additionally, England (under ESA-coordination) entered into a joint project with NASA for SL-2, and as part of this, was offered a chance to submit candidates for review by the SL-2 Investigators' Working Group (IWG) and NASA. Other ESA or national plans for participation in the program are in earlier stages; ESA SL-utilization models project a variable number of European missions through the end of 1985, depending on whether low or high utilization is assumed (1). Demand may be increased through separate national activities, such as the German D-1 and D-4 missions. At present the eventual man power requirements for Europe remain unclear, but could reach significant numbers in the mid or late 80's. These personnel will have to be screened, trained, and medically surveyed; part of these tasks will fall under European responsibility. Certain completed aspects have been presented earlier (2, 3, 4, 5); we will now both review completed events and summarize present status and plans.

PS-Selection Philosophy and Methodology

NASA has defined the criteria that it expects the PS to meet before being considered eligible to fly in the Shuttle SL system. At present, it selects US-PS by letting the Principal Investigators (PI) for a given flight submit eligible candidates from which the Investigators' Working Group picks out the best contingent on qualifying under the medical standards.

For SL-1 ESA chose instead to let each member country nominate candidates who were then to undergo a standardized ESA selection program, prior to being submitted to NASA (Table I). ESA's approach yielded more than 2,000 respondents at the national level

	US	EUROPEAN
INITIAL SOURCE OF CANDIDATES	P.I. RECOMMENDED	RESPONSE TO SEPARATE NATIONAL SELECTION PROGRAMS
1ST LEVEL SCREENING	IWG - INTERVIEWS	NATIONAL SCREENING AND TESTING PROGRAMS (VARIOUS LEVELS OF COMPLEXITY)
2ND LEVEL SCREENING		ESA PRESCRIBED TECHNICAL, MEDICAL, AND PSYCHOLOGICAL SCREENING (SIMILAR TO NASA MS STANDARDS)
3RD LEVEL SCREENING	NASA PRESCRIBED PROGRAM (SPECIAL PS STANDARDS DIFFERENT FROM THOSE OF CAREER ASTRONAUTS)	NASA PRESCRIBED PROGRAM (SAME STANDARDS AS FOR US PS CANDIDATES)

Table I Major Differences Between European and US SL-1 PS Selection Philosophy and Practice (2)

(over 700 from Germany), who then underwent national screening and testing programs of various complexity before being recommended to ESA. Each of 12 eligible countries (plus ESA as an organization) were allowed up to 5 nominations; however, only eight of the participants submitted their full complement of 5, for a grand total of 53.

The 53 candidates were then submitted by ESA to technical and scientific qualification reviews which were followed by psychological and medical screening of those found acceptable (Table II). This process decreased the number to 4 fully eligible candidates; a further internal ESA selection reduced the list to 3 names that were submitted to NASA, and these three persons finally began their career with ESA in mid 1978. One of these 3 should be the first European scientist aboard SL-1.

NUMBER OF CANDIDATES NOMINATED BY MEMBER STATES (INCLUDES 4 DIRECTLY PROPOSED BY ESA)	53
QUALIFIED AFTER TECHNICAL AND SCIENTIFIC SCREENING	12
QUALIFIED AFTER COMBINED PSYCHOLOGICAL SCREENING, MEDICAL SCREENING, AND SPECIAL TESTING	4

Table II SL-1 Payload Specialist Selection - ESA Level Reduction of Candidates Through Successive Screening (3)

Medical Selection Standards

The health and physiological status requirements were variously expressed in the national screening procedures in Europe as well as differing between the NASA and final ESA conducted programs.

NASA has set up less strict PS medical standards (6) in line with the policy to widen the field of applicants for this position, while ESA (7), viewing its PS as career person eligible for multiple missions, had chosen to apply to the candidates screened in Europe medical standards similar to those used for NASA Mission Specialists (MS), i.e. career scientist astronauts (8). Table III shows NASA MS and and ESA PS medical standard similarities as well as NASA PS and ESA PS medical standard differences.

ITEM	PS (EUROPEAN)	MS (US)	PS (US)
HEIGHT (CM) (RANGE)	155 - 190	153 - 193	NOT SPECIFIED
HEARING	500Hz/1000Hz/2000Hz	500Hz/1000Hz/2000Hz	500Hz/1000Hz/2000Hz
(MAX.DB LOSS) BETTER EAR	30 25 25	30 25 25	35 30 30
(MAX.DB LOSS) WORSE EAR	35 30 30	35 30 30	NOT SPECIFIED
VISION (DISTANT)			
UNCORRECTED	20/100	20/100	NO LIMIT
CORRECTED	20/20	20/20	BETTER THAN 20/40 BETTER EYE
VISION (NEAR)			
UNCORRECTED	NO LIMIT	NO LIMIT	NO LIMIT
CORRECTED	20/20	20/20	BETTER THAN 20/40 BETTER EYE
REFRACTION (MAX.SPH)	+2.5/-2.0	+2.5/-2.0	NOT SPECIFIED
REFRACTION (MAX.CYL)	+2.0	+2.0	NOT SPECIFIED
VISUAL FIELD (MAX.CONTRACT)	15°	15°	30°
PHORIAS	SPECIFIED	SPECIFIED	NOT SPECIFIED
VISION (DEPTH)	SPECIFIED	SPECIFIED	NOT SPECIFIED
VISION (COLOR)	SPECIFIED	SPECIFIED	NOT SPECIFIED
JOINTS (MOTION)	SPECIFIED	SPECIFIED	NOT SPECIFIED
BLOOD PR (MAX.S/D)	140 / 90	140 / 90	160 / 100
RADIATION (PRIOR MAX.)	SPECIFIED	SPECIFIED	NOT SPECIFIED

Table III Differences in Space Flight Medical Standards (2)

After the completion of the varied national testing programs, ESA carried out its standardized clinical testing in France (Centre Principal d'Expertise du Personnel Navigant, Paris) and Holland (Aeromedical Department of the Royal Netherlands Air Force, Soesterberg). Selected results have been presented earlier (2, 3, 9).

Special Testing

Besides clinical type screening, ESA wanted to insure the adequacy of its submitted candidates by introducing more thorough psychological testing (7c) as well as special physiological stress testing (7b).

The psychological testing was based on a program originally developed and successfully employed by the DFVLR-Institut für Flugmedizin in the selection of cockpit crews for civil airlines, and subsequently modified according to experience with selection of crews for underwater habitats and for the SL simulation ASSESS II (10). Also, a separate English test was added for PS selection, as the psychological testing included only a brief evaluation of this capacity. Summary reports of the psychological screening have also been presented before (2, 11).

S P E C I A L T E S T S

TEST NAME	BRIEF DESCRIPTION
TREADMILL (PLUS ASSOCIATED 24HOUR ECG AND MINIMAL ANTHROPOMETRY)	FIXED PROTOCOL IN 3 MINUTE STEPS TO MAXIMUM 18% GRADE AND 8 KM/HOUR SPEED.
LOWER BODY NEGATIVE PRESSURE	STAGED PROTOCOL TO MAXIMUM -50 MM HG.
CENTRIFUGE	SHUTTLE LAUNCH PROFILE, REENTRY PROFILE, AND $3G_Z$ TOLERANCE RUNS.
VESTIBULAR TESTS	COMBINATION OF CALORIC TESTING, VESTIBULO-OCULAR, VESTIBULO-SPINAL, OTOLITH PROVOCATIVE TESTING.
ZERO-G FLIGHTS	SEQUENCES OF 10 - 15 SECONDS OF ZERO-G.
PSYCHOLOGICAL TESTS	NOT PART OF THE FORMAL "SPECIAL TESTS" BUT INCLUDED HERE BECAUSE OF INSIGHT PROVIDED INTO CERTAIN CHARACTERISTICS STRONGLY TIED IN WITH PHYSIOLOGICAL RESPONSE.

Table IV SL-1 ESA PS Screening: Description of Special Tests (5)

Additional physiological stress testing (Table IV) was introduced in order to reduce the chance that candidates later demonstrate untoward response when exposed to space flight stresses, and simultaneously to allow novice applicants (who may lack even aviation experience) early in the program the opportunity to personally experience space flight stresses (launch, vestibular disorientation, O-g, re-entry, maximum physical stress) in order to assist them in better judging their motivation for this activity.

The distribution of failures resulting from the special tests according to ESA standards are shown in Table V. Reported are results for the national German examinations as well as summaries of the ESA selection that followed. The reported ESA data were collected both at the DFVLR-Institut für Flugmedizin in Bonn-Bad Godesberg and the RAF Institute of Aviation Medicine in Farnborough.

STRESS TEST	NO. OF FAILURES*	
	FRG**	ESA***
EXERCISE STRESS TEST (TREADMILL)	0	1
ORTHOSTATIC TOLERANCE TEST (LBNP)	2	1
CENTRIFUGE TESTS	3	1
VESTIBULAR TESTS	3	1
ZERO-G FLIGHTS	1	0
24HOUR ECG MONITORING	0	1

*CANDIDATES OFTEN FAILED IN MORE THAN ONE FIELD

**NUMBER TESTED: 14, QUALIFIED: 11

***NUMBER TESTED: 11, QUALIFIED: 8

Table V SL-1 Payload Specialist Selection
Special Testing: Distribution of Failures (2)

The use of special stress testing was justified with ESA's immediate goals of getting the best candidate. However, one should mention that the interpretation of these tests in terms of pass/fail decisions can be difficult, mainly because of the lack of test values encountered in a normal healthy population and adjusted with account to age, sex or anthropometric data. As a consequence, contrasting applications of special stress tests

remain abundant: e.g. the absence of Lower Body Negative Pressure (LBNP) and vestibular testing in recent NASA selections and their inclusion in ESA and Russian screening programs.

Apart from the above mentioned difficulties in interpretation of selected results in terms of "normality", the special tests proved useful in demonstrating significant responses in some candidates who had previously been declared "clinically healthy". Examples of such stress test results that assisted in the judgement of medical fitness for space flight included

- Significant ST segmant depression during exercise stress testing
- Inappropriate high pulse and presyncope during $3+G_z$ exposure
- Inadequate cardiovascular response, including presyncope, to repeated (x3) orthostatic stress using the LBNP
- Discovery of 2 : 1 Wenckebach block on 24 hour ECG tracings
- Marked heart rate swings, nausea and vomiting during O-g flight
- Excessive asymmetry of vestibular response to various stimuli.

More detailed discussions of the special test results have been presented elsewhere (5,12).

Future Selection

The handicap of non guaranteed entry points for European PS complicates the evolution of European PS selection philosophy. For instance, for SL-2 eight semifinalists included six Americans and two British candidates, but the final selection led to four Americans. Compared to the ESA SL-1 candidates, the British candidates had not been screened as thoroughly on the national level before being submitted to NASA for the IWG and the NASA medical evaluations. On the other hand, the individual countries naturally tend against exposing their candidates to an overly extensive selection protocol if the chance of final participation is not relatively secure. In fact, as part of the national selection preceding the final ESA selection for SL-1, only Germany chose to expose its national candidates to the same rigorous procedure that officially only awaited the final ESA candidates. Increasing transfer of responsibility from NASA to ESA as well as a careful application of a waiver policy developed in coordination between ESA and NASA should help to improve future selection procedures.

Payload Specialist Training

For SL-1, a total of 5 PS will be trained (2 US and 3 European). Later in the program, 1 US and 1 European candidate will be designated "Flight Payload Specialist". To the point of this differentiation, all PS will follow a common payload training schedule. According to the philosophy of SL-1, the PS will be required to be completely knowledgeable about all of the experiments on board. In addition, the 2 PS chosen to fly will focus upon procedures and flight mission operations, while those PS assigned to earth-based duties will concentrate upon operational control and scientific support aspects of paylaod operations. Requirements for PS training activities (together with guidelines and constraints, responsibilities, resources and schedules) are documented in the NASA SL-1 PS-Integrated Training Plan (13). ESA has defined the European training phase in a separate PS Training Plan (14). Though SL-1 is possibly atypical because it is such a diverse mix of experiments and disciplines, analysis of these documents should be an instructive starting point to the question of PS training in general.

Guidelines and Constraints

The NASA Training DOcument (13) defines the following guidelines and constraints for SL-1:

1. PS training will maximally be accomplished using flight or bread board hardware at the Principal Investigator sites and during payload physical integration activities.

2. PS will be trained on those Shuttle and Spacelab skills necessary to enable them to live and work safely and effectively in the space flight environment. Among these are emergency procedures, standard operating procedures, habitability, lighting, and communications.

3. PS will follow a training schedule which enable them to execute all payload procedures.

4. Specialized training facilities are provided for the Command and Data Management System (CDMS), but the degree and fidelity of simulation will be held to the minimum required to impart adequate operational competence.

Training Categories

We should understand that there are 2 categories of PS training: mission independent and mission dependent.

Mission independent training is that which is not directly related to the payload scientific objectives but which is essential for functioning as part of the Shuttle team. The training required to develop these skills will include safety aspects, habitability features, and emergency manoeuvers, like medical emergency, survival operations, and emergency pad egress.

Mission dependent training centers about payload experiment operation. Most of it is defined by individual investigators and conducted at the experimenters' site. It is planned to provide software simulation training of experiments where operations are carried out via the Spacelab Data Display Unit (DDU)/Key Board (KB) and the Command and Data Management System (CDMS).

PS mission independent training, as planned by the NASA Johnson Space Center Crew Training Division, is summarized in Table VI. It comprises a total of 143 teaching hours and is structured into 4 blocks: orientation lessons, orbiter systems lessons, crew systems lessons, and space system lessons. The curriculum foresees only a minimum of directly medical related lessons.

	HRS
ORIENTATION LESSONS:	
SHUTTLE PROGRAM ORIENTATION	4
SHUTTLE STRUCTURES OVERVIEW	3
SPACELAB STRUCTURES OVERVIEW	2
SPACEFLIGHT PHYSIOLOGY	2
	11
ORBITER SYSTEMS LESSONS:	
ORBITER SYSTEMS OVERVIEW	3
CAUTION & WARNING, FIRE	3
AUDIO SYSTEM	1
AUDIO/LIGHTING OPERATION	1
ENVIRONMENTAL CONTROL & LIFE SUPPORT SYSTEM	2
ELECTRICAL POWER DISTRIBUTION & CONTROL SYSTEM	2
GENERAL PURPOSE COMPUTER (GPC) OVERVIEW	2
	14
CREW SYSTEMS LESSONS:	
CATHODE RAY TUBE (CRT) CAMERA	1
COMMUNICATIONS EQUIPMENT I	1
COMMUNICATIONS EQUIPMENT II	1
COMMUNICATIONS EQUIPMENT PROCEDURES	2
CREW STATION LOCATION CODING	1
CREW STATION FAMILIARIZATION	2
FOOD SYSTEM AND DINING	1.5
FOOD SYSTEM AND DINING EQUIPMENT	2
FOOD PREPARATION AND DINING PROCEDURES	3
WASTE COLLECTION SYSTEM	2
WASTE COLLECTION PROCEDURES	2
HABITABILITY	2
HABITABILITY EQUIPMENT	1.5
HABITABILITY PROCEDURES	3
RESTRAINTS AND MOBILITY AIDS	1
FOOT RESTRAINT OPERATION	1
RESTRAINTS AND MOBILITY AIDS PROCEDURES	2
MEDICAL EQUIPMENT	2

(CONTINUED)

	HRS
CREW SYSTEMS LESSONS: (CONTINUED)	
MEDICAL EQUIPMENT AND PROCEDURES--I	4
MEDICAL EQUIPMENT AND PROCEDURES--II	4
PORTABLE OXYGEN SYSTEM	2
FIRE EXTINGUISHER	0.5
EMERGENCY EQUIPMENT PROCEDURES	2
PERSONAL RESCUE SYSTEM	2
PRELAUNCH	1.5
PRELAUNCH INGRESS/EGRESS	3
LAUNCH PAD ESCAPE	8
POSTLANDING	2
POSTLANDING EGRESS EQUIPMENT	2
DESCENT DEVICE OPERATIONS	1
LIFE RAFT OPERATIONS	2
POSTLANDING EGRESS (NORMAL/EMERGENCY)	4
	69
SPACE SYSTEM LESSONS:	
SPACELAB SYSTEMS OVERVIEW	2
ELECTRICAL POWER AND DISTRIBUTION SYSTEM	4
ENVIRONMENTAL CONTROL SYSTEM	4
EPDS/ECS OPERATIONS	2
COMMON PAYLOAD SUPPORT EQUIPMENT	2
COMMAND & DATA MANAGEMENT HARDWARE SYSTEMS	4
CDMS KEYBOARD/DATA DISPLAY UNIT OPERATION	3
CDMS COMPUTER SOFTWARE MANAGEMENT	4
CDMS OPERATION--I	4
CDMS OPERATION--II	4
CDMS OPERATION--III	4
CDMS OPERATION--IV	4
CAUTION AND WARNING SYSTEM	1
AUDIO/CCTV SYSTEMS	1
AUDIO/LIGHTING/CCTV SYSTEMS	2
CPSE AIRLOCK OPERATION	4
	49

Table VI SL-1 PS Orientation and Training
Mission Independent Lessons (4)

Training is devided into tours with NASA Marshall Space Flight Center (MSFC) having overall responsibility for planning, integration, implementation and evaluation of PS training, NASA Johnson Space Center (JSC) providing the bulk of mission independent training that is not peculiar to launch and landing sites, and ESA/SPICE ensuring the availability of European experiment training; part mission simulations are also foreseen for SL-1.

A preliminary training schedule valid for both American and European PS is shown in Table VII. (The schedule is based on Dec. 1980 as launch date for SL-1; meanwhile, launch has been postponed to 1981; accordingly, schedule dates may slide to later times also.)

On the European scene, the training responsibility rests with ESA/SPICE (Spacelab Payload Integration Center, Europe); the health and safety aspects of this training are insured through the assignment of an ESA International Medical Board whose work is carried out with the help of Medical Consultants as well as a Crew Surgeon and his Deputy (Table VIII). This group of experts oversees the initial selection as well as the following health surveillance of the crew. With this team, the Board can make rational judgements on the specific health and safety aspects of all the European experiments as well as on the general health and safety of European PS in all (European and American) phases of their activity.

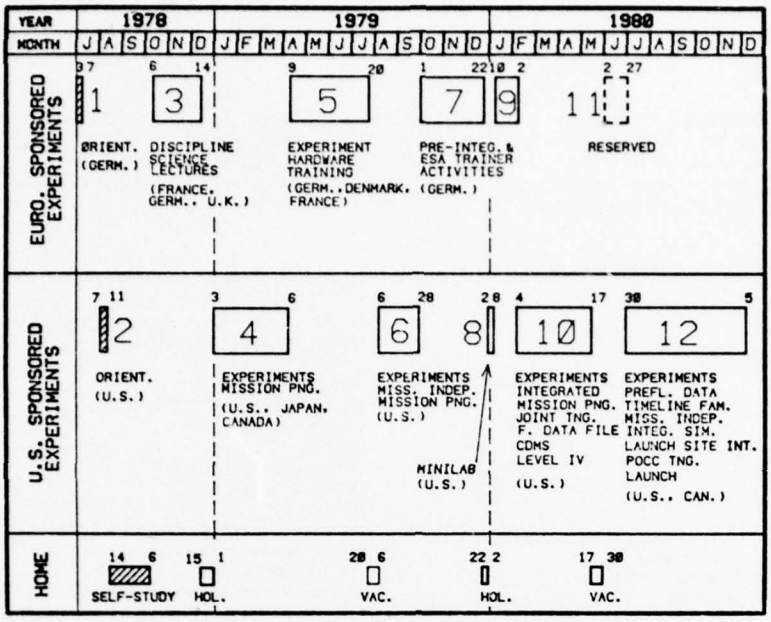


Table VII SL-1 PS Training Schedule
Tours of Duty (13)

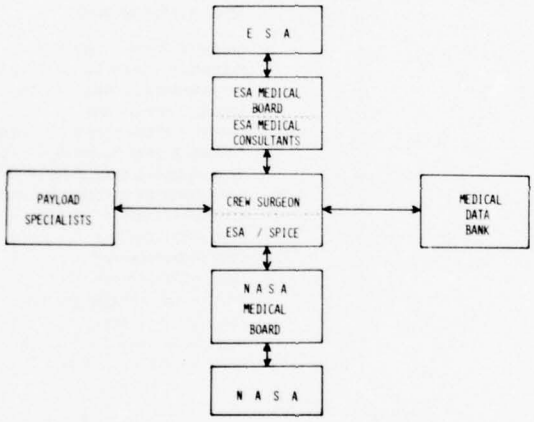


Table VIII Interfaces in SL-1 ESA PS Health and Safety Surveillance

European Training Philosophy

ESA has set up a European training plan that consists of 5 phases, each with a distinct objective (Table IX).

PHASE 1: FAMILIARISATION WITH EXPERIMENTAL OBJECTIVES (LITERATURE PROVIDED BY PRINCIPLE INVESTIGATOR)

PHASE 2: DISCIPLINE ORIENTED LECTURING BY THE INVESTIGATORS

PHASE 3: HARDWARE FAMILIARISATION AND HANDS-ON TRAINING ON EXPERIMENT LEVEL AT DIFFERENT IDG DEVELOPMENT SITES

PHASE 4: SYSTEM LEVEL TRAINING IN OFF-LINE CREW TRAINING FACILITY FOLLOWED BY MISSION SIMULATIONS

PHASE 5: ACTIVE INVOLVEMENT IN ON-LINE INTEGRATION ACTIVITIES

Table IX SL-1 ESA PS Training Phases (14)

With this program it is expected that the crew will obtain the necessary scientific background through lectures and discussions with PI during phases 1 and 2 which were scheduled from July through December 1978. The familiarization with the man/machine interface on the experiment level is obtained through phase 3. The crew will be readied in phase 4 to play an active role in the flight hardware integration activities. Finally, activities in the on-line integration of phase 5 will include development of installation, test and operational procedures, physical integration and testing of experiments, optimization of experiment performance, upgrading of operational software and updating of the task distribution between PS and MS on-board (14).

In reviewing the training plans, it becomes obvious that most of it is executed in very diverse set of locations. This process will prove a great strain on the trainees (and their families) and certainly is a long way of from the idealized goal of scientist investing a limited time in preflight preparations. Furthermore, the trainee is being prepared to be a multi-disciplinary scientist and technician and must do many experiments other than his own; his unique capability for any single experiment play less dominant a role than might have been envisaged. It seems that in the development for SL-1 PS and MS roles assimilate. It is not surprising that NASA has considered PS selection out of the NASA Mission Specialist pool as a cost effective way to go. For Europe this development means a further justification for the ESA PS career status.

Biomedical Training

As part of the overall training program, whether it may develop for SL-1 or later flights, is the separate consideration of a mission independent biomedical training for European PS. This category of training was felt in need of expansion for the reasons given in Table X.

JUSTIFICATION FOR EXPANDED ESA INVOLVEMENT	
ESA PAYLOAD SPECIALISTS	
1)	ARE CAREER EMPLOYEES
2)	REQUIRE THIS INFORMATION TO MAKE INFORMED JUDGEMENTS ON THEIR PARTICIPATION
3)	CAN BETTER CONTRIBUTE TO FLIGHT SPECIFIC LIFE SCIENCES EXPERIMENT PROTOCOLS
4)	CAN BETTER CONTRIBUTE TO THE MAINTAINANCE OF THEIR OWN (AND THEIR FELLOW TEAM MEMBERS) HEALTH AND SAFETY
5)	WILL BETTER APPROXIMATE THE BIOMEDICAL EXPERIENCE OF NASA MISSION SPECIALISTS
6)	WILL BE ABLE TO ABSORB THE EVENTUAL NASA BIOMEDICAL TRAINING EXPOSURE BOTH WITH GREATER EASE AND HIGHER RETENTION

Table X PS Mission Independent Biomedical Training
Justification for Expanded ESA Involvement

The duration of this training evolved from theoretical consideration into an actual approximate 2 months of total training time (Table XI), broken down into 2 weeks (or 80 hours) of exposure to clinical medicine topics, 2 weeks to aerospace physiology, and 4 weeks exposure to life sciences hardware independent of mission. Currently, the European PS have about 2 - 3 weeks of such training planned into their schedules annually until launch with an initial 2 weeks session having been completed in August 1978 at the DFVLR-Institut für Flugmedizin.

TYPE OF TRAINING	JUSTIFICATION	
CLINICAL	APPROXIMATELY TWO WEEKS WERE UTILIZED TO PROVIDE INTENSIVE MULTI-SPECIALTY ORIENTATION TO CLINICAL (EMPHASIS FIRST-AID AND EMERGENCY) DIAGNOSIS AND TREATMENT AS PREPARATION FOR LONGER DURATION SPACE FLIGHTS	
AEROSPACE PHYSIOLOGY	MANY BASIC AIR FORCE PHYSIOLOGY COURSES REVIEW ALL BASICS IN ONE WEEK AND AN ADDITIONAL WEEK IS FELT THE MINIMUM NECESSARY TO PROVIDE PERSONAL EXPOSURE TO VARIOUS PHYSICAL STRESSES	
SPACE LIFE SCIENCES EXPERIMENT HARDWARE FAMILIARISATION	A MINIMUM OF FOUR WEEKS CAN ALLOW FAIRLY INDEPTH EQUIPMENT FAMILIARISATION IN THE FOLLOWING GROUPS:	
	(1) CV/PULM./ANTHROPOMETRIC	(1 WEEK)
	(2) NEUROLOGY/VESTIB./AUDIOVISUAL	(1 WEEK)
	(3) BIOCHEM./ENDOC./RENAL/HEMAT./NUTRITION/CIRCAD. EFFECTS	(1 WEEK)
	(4) ZOOLOGY/BOTANY/MICROBIOLOGY	(1 WEEK)

Table XI PS Mission Independent Biomedical Training
Justification for Extended Duration for ESA PS

In contrast, the NASA biomedical training planned for SL-1 PS provides 18.5 hours for medical and emergency training, and 21 hours for supporting crew systems and habitability training. Clearly, the ESA training plan for PS tries to include a depth of exposure more as would be found in a NASA MS training plan.

Simulation

At present, NASA foresees the use of simulators for mission independent training on Shuttle and Spacelab systems. Activities in simulators involve the Shuttle mission simulator with the crew station, the Spacelab simulator with a representation of the scientific airlock, and the groundbased Mission Control and Payload Operation Control Centers.

TESTABLE SKILL OR QUALITY	FIDELITY OF TEST OF SKILL DURING TRAINING IN RELATION TO TEST DURING ACTUAL SPACE FLIGHT* CONCEPT A (BASIC TRAINER)	CONCEPT B (MISSION SIMULATION TRAINER)
1) ENGLISH LANGUAGE	***	****
2) TECHNICAL KNOWLEDGE (BIOMEDICAL INCLUDED)	***	****
3) TECHNICAL REASONING	**	***
4) MATHEMATICAL REASONING (APPLICATIONS)	***	****
5) MEMORY (VISUAL)	****	****
6) MEMORY & COMPREHENSION (ACOUSTIC)	**	****
7) CONCENTRATION	**	****
8) FIELD OF ATTENTION	*	****
9) WORKING SPEED	*	***
10) EXPERIMENTAL DATA MANAGEMENT	**	***
11) SIMPLE COORDINATION (KEYBOARD RESPONSE)	***	****
12) COMPLEX COORDINATION (MULTI-TASK-, HAND-FOOT)	0	***
13) INSTRUMENT AND EQUIPMENT HANDLING	*	***
14) PRACTICAL EQUIPMENT REQUIREMENTS (BLOOD DRAWS, INJECTIONS, INCISIONS AS BIOMEDICAL EXAMPLES)	0	***
15) FIRST AID RESPONSE	0	***
16) EQUIPMENT REPAIR	*	***
17) STRESS RESISTANCE TO		
A) HIGH WORKLOAD	*	****
B) CONFINED & CONGESTED LIVING CONDITIONS	0	***
C) EMERGENCIES, PERSONAL & EXTERNAL	0	**
D) O-G INFLUENCE	0	0
18) PERSONALITY TRAITS/BEHAVIOR	*	***
19) VITALITY AND PHYSICAL FITNESS	0	***

*CODE: 0 = 0 - 5
* = 5 - 25
** = 25 - 50
*** = 50 - 75
**** = 75 - 100

Table XII Testable Skills or Qualities Using Simulations

For mission dependent training, there will be a Payload Specialist Training Complex (PSTC) providing equipment which allows simulation of experiment interactions with the Spacelab Digital Display Unit/Keyboard and the Command and Data Management System.

ESA has emphasized the necessity to train the Payload Specialists in their major forms of interaction with the other elements of the system, i.e.: - with payload, - with Mission Specialist, - with Principal Investigator, - with Orbiter/Spacelab environment. These objectives can be met only to a limited degree with the facilities presently available. Therefore, a joint ESA/DFVLR Study Group has identified a Spacelab Crew Training Facility (SCTF) concept which, by training on the above mentioned interfaces, would allow the individual crew member to adapt to the system and actually learn to function as a team.

The Spacelab crew trainer is under development as a probable joint DFVLR/ESA facility at the DFVLR-site in Porz-Wahn. In addition to crew training it will permit experiment and payload development for future Spacelab flights, medical research on man/machine interfaces, and preflight testing of PS qualities as delineated in Table XII. The proposed training site could become a centralized focus for European payload development and training, and could conveniently supplement the level IV and pre III integration associated training that is scheduled in Europe. It would even enhance selection procedures as one could search for the "best" candidate with this type of training facility through the systematic observation of behavior and performance under mission time line conditions.

ESA-DFVLR have gained their first experience with problems of multidisciplinary payload operation and PS training during the Spacelab simulation ASSESS II (Airborne Science Spacelab Experiment System Simulation) which was jointly performed in 1977 with NASA at the Ames Research Center (16). A medical experiment of the DFVLR-Institut für Flugmedizin belonged to the payload; it allowed evaluation of PS workload, sleep, and biological rhythms through cardiovascular, metabolic, hormonal, and neurophysiological variables measured either continuously or in regular intervals over a total period of 3 days before, 9 days during, and 3 days after the simulated SL-mission. Examples of the results are shown in Fig. 1 - 3. A detailed presentation of the data is given elsewhere (17); the closed mission simulation demonstrated the adaptive character of physiological responses, i.e. the normalization of sleep, but also showed desynchronization of biological rhythms through shifting work schedules as might be expected in space missions.

Physical Training

In closing, a few words should be addressed to the question of training as a means of adapting the human organism to space flight related changes, in particular to weightlessness. Such training prior to space flight will remain difficult to standardize until one has a base of preflight and postflight data on people who have followed prescribed training programs; in the past, preflight training has been largely an individual matter and as such made it difficult to evaluate differences in inflight changes.

These standardized programs must not emphasize excessive physical fitness; disadvantages (experienced by excessively fit personnel) in tolerating orthostatic and immobile conditions have been pointed out before (18). Other authors (19, 20, 21) have indicated the value of adding vestibular training for selected PS candidates, proposing various combinations of otolith and semicircular canal adapting exercises utilizing rotating chairs,

trampolines, roller coaster flights, and parabolic flights.

Whether individual physiological system training programs (cardiovascular, vestibular, etc.) will be established for SL-1 is open. If so, one must filter out the disturbance of adaptive training on the PS medical experiment baseline data; this is particularly significant for vestibular research.

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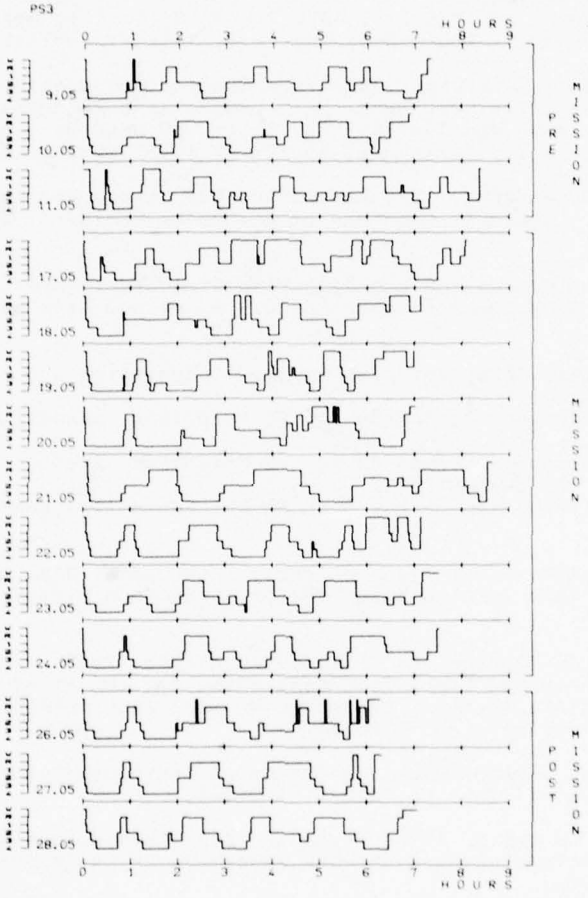


Figure 1 Sleep profiles of a PS participating in the SL-mission simulation ASSESS II.

Abscissa: Time in bed. Ordinate: Wake (W) and sleep stages (1-4), REM (Rapid Eye Movement) stage. Date of each night: Along left margin.

Note: Increase of wake time at the beginning of the mission, also irregularities in sleep stage distribution; both caused by shifts in the rest-activity cycle and through unusual workload (17).

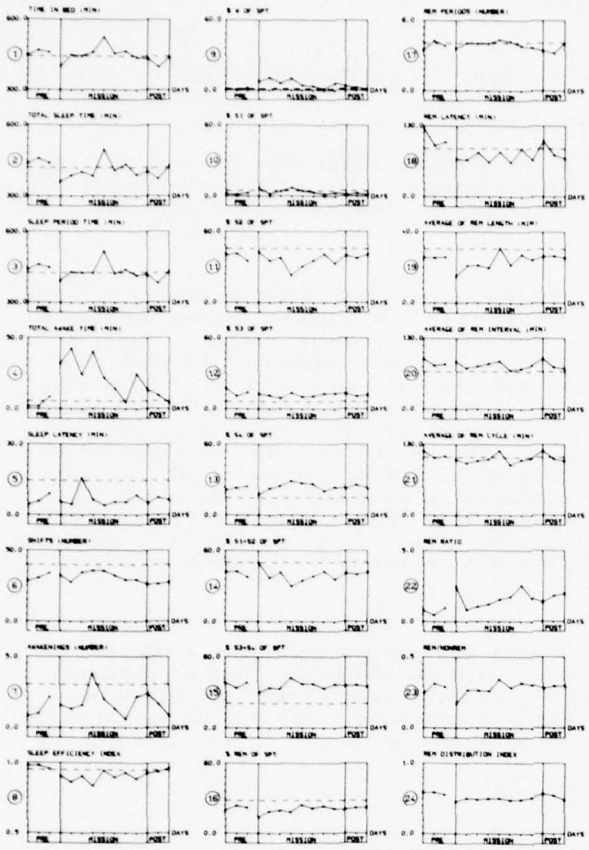


Figure 2

Computer output of sleep characteristics.
Presented are mean values for the PS group participating in ASSESS II.

Note: a) Gradual normalization of lengthened "Total Awake Time", shortened "Average REM Length" towards the end of mission
b) deviation of sleep efficiency index during mission. For probable causes see Figure 1 (17).

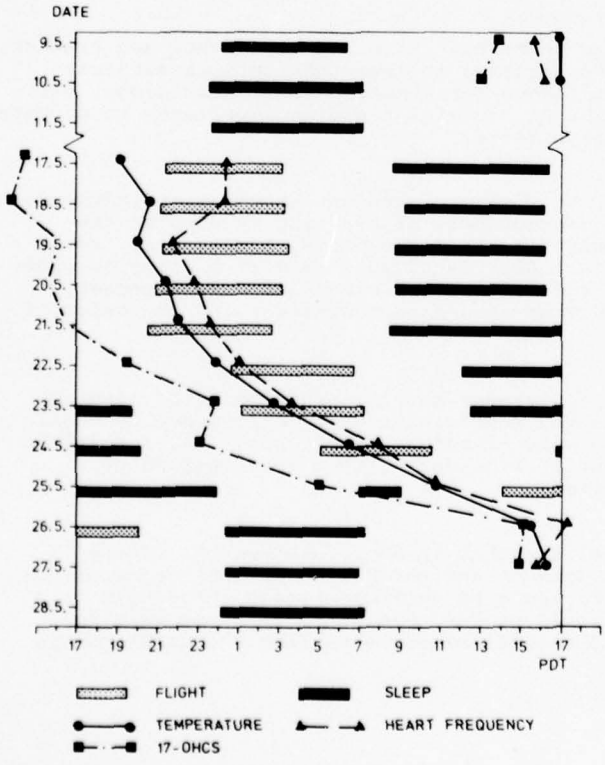


Figure 3

Phase angles of circadian rhythms. Presented are mean values for body temperature, heart rate and 17-OHCS excretion of the PS group participating in ASSESS II.

Note: After the shift of the rest-activity cycle at mission start, body functions adapt with different speed, resulting in transitory abnormal phase relationships (internal dissociation) (17).

DISCUSSION

R. Murray Will you say a word about the use of female candidates for European Payload Specialists?

K. Klein In Europe we had a few female candidates who went through the preliminary selection and screening process and some passed on to advanced screening. There were two left at the time of the final selection process, but they were rejected.

P. Howard May I comment further on the question about women astronauts. The candidate who went farthest in the process eventually failed because she was unable to complete the exercise protocol demanded by the ESA special testing regimen. Now the question is, as Dr. Klein hinted, whether she should have been expected to show proficiency in this test area - whether it was necessary that she should be as strong as a man. I think that the selection program in general was unreal in two respects. The first was that the special tests were in many instances completely arbitrary and the information that they yielded was uninterpretable. The second was that we finished up with Europe's fittest astro-physicist or particle physicist or whatever, yet for the purposes of Space Lab I, that we should have finished up with Europe's most nimble and versatile laboratory assistant. Perhaps we shall remedy that in later flights. The number of different skills which this person will be required to exercise will be large and most of them will be completely divorced from his or her primary professional life and activity.

K. Klein I quite agree with most of what you say concerning the special screening tests. On the other hand, we shouldn't dismiss the whole idea of physical and psychological standards. It is certainly nonsense to require men and women to reach equal levels of strength or oxygen consumption but some standards of performance must be set. Unfortunately, I don't believe we know enough as yet to set appropriate standards for all.

R. Murray When will the first space flight be flown?

K. Klein A new date has not been finalized as yet, but I heard unofficially that it might be as early as 1982, but perhaps not until 1983.

F. Violette I should like to make two comments. First, as a teacher and trainer, I don't believe that sufficient time has been allotted to learn the various subjects assigned to the trainees - only a week for instance for endocrinology, hematology, etc. Second, I do not believe that parabolic flight is a useful training experience to prepare for weightlessness, especially for vestibular effects.

K. Klein It is important to separate mission-dependent and mission-independent training. The Payload Specialists will get a great deal of training related to the mission-dependent experiments planned for that flight, for example, biophysics. But, regarding biomedical matters that are mission-independent, such as microbiology or endocrinology, it would be impossible to extend further the training period to increase knowledge in these areas. Would you restate your second comment regarding the value of parabolic flight?

F. Violette Earlier experience in space travel seems to show that the first 12 hours or so in the space environment would be the best conditioning experience to enable the astronaut to adapt himself or herself to weightlessness conditions. So, I think it is important to set aside a sufficient amount of time during this first period of weightlessness in the space shuttle for adaptation.

K. Klein First of all, I don't believe that 12 hours are enough. There is ample proof that some astronauts (from both Russia and the United States) had problems for up to three days. So, a 12 hour exposure won't be sufficient, and three days is a long time to wait to adapt. Actually, one would prefer that astronauts not wait to adapt during flight but to be fit to carry out their experiments from the first moment of flight.

PHYSIOLOGICAL FACTORS IN SPACE OPERATIONS

Emphasis on Space Shuttle

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SUMMARY

Efforts to determine the physiological effects of null-gravity space flight on humans began in earnest in 1960 with the establishment of the National Aeronautics and Space Administration's (NASA) Life Sciences Program. The early predictions of life scientists about the physiological effects of null-gravity space flight on man before the first manned space mission ranged from extremely severe to none at all. The majority of the predictions were very pessimistic in terms of current knowledge. It has been proven that, with proper life support systems, man can live and work in the null-gravity environment of space for at least 84 days without serious physiological degradation. The recent Soviet flight of 140 days is the longest time man has remained continuously in this environment. The detailed physiological results of this mission will not be available for some time.

The NASA Life Sciences Program began as an integral part of the United States Manned Space Exploration Program. At first, the life scientists assisted in the selection of astronauts and began to assist in the development of life support systems for space flight. Eventually the life scientists established medical operation procedures and conducted preflight and postflight studies to determine the physiological responses of both animals and men during space flight. The Life Sciences Program basic objective was to assure the health and safety of crewmen.

The Life Sciences Program has been a direct and essential contributor to all manned space flight from Project Mercury to the Apollo-Soyuz Test Project. The understanding that has developed from manned space flight allows mankind to be optimistic about the ultimate accommodation of humans to unlimited space activities. At the same time, however, past research indicates a need to continue the investigations of human physiology in several areas in which potentially serious problems have been identified.

Although many of the space-induced changes found in physiological function are of general interest to the biomedical community, they are of particular concern to the NASA. First, they directly affect considerations about flight safety. Second, these phenomena are associated with healthy rather than diseased individuals; they also concern a select group rather than the general population. These reasons relegate most of the studies of these phenomena to the NASA rather than to other Federal agencies such as the National Institutes of Health.

Problems such as space motion sickness, redistribution of body fluids, and cardiovascular deconditioning are of concern in short-duration Space Shuttle flights. The expanded participation of nonastronaut crewmembers or payload specialists in these flights increases the life scientists' interest in the Space Shuttle flights. Problems such as loss of skeletal mass, decreased red blood cell production, and numerous endocrine changes are of more concern on long-duration flights. The Life Sciences Program is therefore concerned with a wide variety of problems that range from the applied to the basic. The common thread is biology; the context is space. Several physiological factors associated with Space Shuttle operations are summarized in this paper including space motion sickness, cardiovascular deconditioning, bone and muscle loss, hematology, fluid and electrolyte changes, reentry g-forces, radiation safety, noise, atmosphere, extravehicular activity, toxicology, nutrition, biowaste, and health maintenance.

DISCUSSION

The Space Shuttle

A new era of space transportation will start in the 1980's with the Space Shuttle's ability to inexpensively transport a variety of payloads into earth orbit. As James Fletcher, the former administrator of NASA, said, "Any discussion of future space initiatives must start with the Space Shuttle, the key to opening near space to quick, easy, and economical access. With the Space Shuttle, operations to and from low-altitude Earth orbit for both manned and unmanned exploration, science, and applications will become routine and relatively inexpensive."

Many participants, representing diverse backgrounds and capabilities, will work routinely in the environment of space, and they will be taken there and returned by the Space Shuttle. The Space Shuttle is being designed and built to take advantage of the most efficient

characteristics of both humans and complex machines. This combination, coupled with the flexible characteristics of the Space Shuttle, will provide an efficient system for future national space program activities. With its versatility and reusability, the Space Shuttle will truly open the door to economical and routine use of space.

As a transportation system to Earth orbit, the Space Shuttle will offer the capabilities of such earthbound carriers as trucks and airplanes. The Orbiter is designed to carry into orbit a crew of up to seven, including scientific and technical personnel. On a standard mission, the Orbiter can remain in orbit for 7 days, return to the Earth with personnel and payload, and land like an airplane.

The characteristics of the Space Shuttle will no longer require that the crew be limited to astronauts but will now accommodate scientists and technicians. The maximum acceleration which crewmembers and passengers will experience during launch will be 3g and during a typical reentry 1.5g. These accelerations are about one-third the levels experienced on previous manned space flights; however, the reentry g-component is in the z-axis.

The astronaut and space worker of the future can look forward to many other features of the Space Shuttle including a standard sea-level atmosphere. The nominal duration of a Shuttle mission may be extended to as long as 30 days if the necessary consumables are provided. After the orbital operations, the deorbiting maneuvers are initiated and Shuttle reentry is made into the Earth's atmosphere at a high angle of attack. At low altitude, the Orbiter goes into a horizontal flight path for an aircraft-type approach and landing. A 2-week ground turnaround is the goal for reuse of the Space Shuttle Orbiter. The Space Shuttle may be used in many ways including the operation of satellites, satellites with propulsive stages, space laboratories, or combinations as appropriate.

The Shuttle Orbiter can deliver into orbit a payload of 29,500 kg (65,000 lb). This payload may be up to 18 m (60 ft) long and 5 m (15 ft) wide.[1] The Orbiter is comparable in size and weight to a modern transport aircraft such as the DC-9. It has an empty weight of approximately 68,000 kg (150,000 lb), a length of 37 m (122 ft), and a wing span of 24 m (78 ft). Although the crew compartment is sized for seven crewmembers and passengers, it may hold as many as 10 people in emergency operations. The Orbiter cabin is designed as a combination working and living area. The pressurized crew compartment has a large volume, 71.5 m^3 (2525 ft^3) when compared to the 22 m^3 (600 ft^3) of the Apollo spacecraft. The upper section, or flight deck, contains displays and controls used to pilot, monitor, and control the Orbiter, the integrated Shuttle vehicle, and mission payloads. Seating for as many as four crewmembers can be provided. The midsection contains passenger seating, living area, an airlock, and avionics equipment and compartments. The aft hatch in the airlock provides access to the payload bay.

The payload-handling station, located in the aft section of the flight deck, contains displays and controls required to manipulate, deploy, release, and capture payloads. The person at this station can open and close payload bay doors; deploy the coolant systems radiators; deploy, operate, and stow the manipulator arm; and operate the lights and television cameras mounted in the payload bay. Two closed-circuit television monitors display video from the payload bay television cameras for monitoring payload manipulation.

A versatile extravehicular capability is provided by an airlock, two space suits, and mobility aids. A variety of tasks can be performed during extravehicular activity (EVA) to support either the Orbiter or its payloads.

The Life Sciences Program

The NASA Life Sciences Program principally supports manned space flight and the Space Shuttle in furthering capabilities to exploit and explore space. A major goal of the Life Sciences Program is to understand and reduce any adverse effects of the space environment on humans so that a varied segment of the population can participate directly in space and to develop the foundation for man's extended presence and operations in space. The Life Sciences Program pursues its goals using a diverse set of disciplines. The NASA Life Sciences Program conducts research and development activities that require the services of physicians, biologists, psychologists, chemists, and engineers.

Because of the nature of the physiological changes noted in the null-gravity environment to date, the original full-time physiological monitoring has been supplanted by monitoring only during periods of high activity.[2] More sensitive and elaborate measurement systems are used part-time in an attempt to determine the etiology of some of the subtle physiological changes that have been identified as a result of previous space flight. By the use of more sensitive physiological measurement tools, several additional subtle physiological changes will no doubt be revealed. It is important to note that all physiological changes detected in space thus far were completely reversible. That is, the physiology returned to normal within a very brief period, usually a few days after return to Earth. A healthy crewman's ability to adapt in the null-gravity environment and to readapt to the one-g environment has proven to be excellent.

The physiological changes observed have been so subtle that the detection frequently required sensitive instruments coupled with the use of provocative tests such as tilt tables, lower body negative pressure devices, bicycle ergometers, and rotating t-chairs. In view of the rather minimal physiological changes induced by null-gravity space flight to date, the question arises as to what sort of physiological measurements should be made on future space travelers. On the relatively brief flights, monitoring of the crewmen during high-activity

periods will suffice supplemented by selected, well-planned, mission compatible, medical studies.

On February 7, 1978, the NASA issued an Announcement of Opportunity for Life Sciences investigations on dedicated Space Shuttle/Spacelab Missions 1981 through 1983.(3) In it appeared the following excerpt from the National Academy of Sciences study, Scientific Uses of the Space Shuttle (Space Sciences Board, National Research Council, National Academy of Sciences, 2101 Constitution Avenue, Washington, D.C. 20418, 1974, page 154).

> "The Shuttle Era will provide the first opportunity to carry out a thorough experimental program in the life sciences under conditions approximating those of ground-based laboratories . . . . In addition to biomedical investigations relevant to man's well-being in space, the basic principles of biology and medicine can be examined using the zero-gravity environment as a research tool."

The NASA plans to make the Shuttle the basis of a highly versatile space life sciences laboratory capable of supporting applied and basic biological, biomedical, behavioral,and technological investigations. The NASA has received many flight experiment proposals as a result of this announcement. Those flight experiments selected as a result of the announcement will undergo a detailed definition study before final flight assignments are made. Because several space flights were covered by the announcement, the investigators were encouraged to propose multimission experiments if needed.

The primary areas of research to be pursued in space and on the ground are space motion sickness, cardiovascular deconditioning, bone mineral loss, muscle loss, red blood cell loss, and fluid and electrolyte loss. These areas of current emphasis have emerged from systematic examination of bodily systems in prior manned spaceflight experiments. In addition to the major areas of research in the life sciences for the Shuttle Era, one should note that considerable interest exists in the physiology of the reentry G_z-forces exerted on the crewmen and passengers; of radiation exposure; and of environmental factors such as noise, atmosphere, EVA prebreathing, hygiene, and toxicology. Additional operational factors, such as food, nutrition, and health stabilization will also be investigated. Each of these factors associated with manned space flight will be reviewed and its mission effect, if any, will be noted.

Space Motion Sickness

The absence of Earth gravity during space flight has a potential effect on those sensory systems that are gravity- or acceleration-sensitive, such as the vestibular system. Physiological problems involving the vestibular system have been observed during previous manned space flights, the most striking problem being space motion sickness. Approximately 30 percent of the Apollo and 55 percent of the Skylab crewmembers experienced some symptoms of space motion sickness during space flight. In all cases, the symptoms of space motion sickness were confined to the early portion of the flight and complete recovery had taken place within 3 to 5 days of the start of the mission.(4)

During the Space Shuttle operations, three factors increase concern about the incidence of space motion sickness that is anticipated.

1. Many Space Shuttle flights will be short duration with high workloads planned during the initial days in orbit. Performance decrements due to illness could easily affect mission success.

2. The increased volume of Shuttle will permit extensive movement by the crewmembers. It is postulated that this movement may contribute to the onset of symptoms of space motion sickness.

3. Space Shuttle crews and passengers will include a significant number of individuals previously inexperienced with the unusual gravito-inertial force environments. This inexperience with the null-gravity environment of space could contribute to the onset of symptoms of space motion sickness in a higher percentage of the individuals onboard. Most life scientists agree that better understanding of the causes of space motion sickness will be essential to the ultimate development for means of its control, and as a result the NASA has initiated a program of ground-based research with humans and animals. These research studies will use appropriate electrophysiological neuroanatomical, behavioral, and biochemical methodologies.

In pursuing these studies, attention will be focused on two prevailing theories on the cause of space motion sickness. One of these, the sensory conflict theory, postulates that the sickness is the result of a neural mismatch between the information received from the spatial senses and that from previous experience. The second, the fluid shift theory, postulates that space motion sickness results from the headward shift of body fluids in weightlessness and the ensuing pressure changes in the labyrinthine fluids.

Flight experiments will be needed to investigate and confirm in null gravity the hypotheses that cannot be adequately studied in the one-g laboratory of Earth. Three such vestibular flight experiments to examine the sensory conflict hypothesis are planned for the first Spacelab flight, and additional investigations will be done on the ensuing dedicated flights.

Research on the development of predictors of susceptibility to space motion sickness will focus on several related approaches. One of these involves attempts to establish positive correlations between susceptibilities in different provocative test environments. Particular

emphasis is being placed on the use of stimuli that introduce sensory conflict and on comparisons between susceptibility during ground-based test and null-gravity parabolic flight. Another approach is to determine the correlation between susceptibility and other response parameters such as vestibular reflexes, psychodynamic traits, and biochemical factors. Finally, innate or learned behavioral and physiological adaptability to stressful environments is being evaluated as having possible predictive value. Despite the insights that should be gained as a result of these ground-based studies, it is anticipated that the final validation of predictive tests will require a series of controlled experiments with individuals who will fly on Space Shuttle missions. Many needed elements of this validation process are embodied in a test program which is currently under development and which will commence with the Shuttle flights during the Orbital Flight Test (OFT) phase.

Two approaches are being followed with regard to the development of effective countermeasures for space motion sickness. The most promising of these at present involves the use of anti-motion sickness medications. Advances have been made in the identification of highly effective drugs that can be administered orally, transdermally, or intramuscularly. Research is being pursued to establish the overall efficacy of these drugs in different provocative motion environments. Despite their usefulness, anti-motion sickness drugs may exact penalties in the form of detrimental side effects. Therefore, additional research is required to examine more thoroughly the behavioral and physiological consequences of using drugs as a countermeasure.

In addition to drugs, the development of practical vestibular adaptation training methods continues to be of great interest. In this area, efforts are being made to acquire more information related to the acquisition, retention, and transfer of adaptation. With regard to training, unique research that uses biofeedback techniques is being performed. As with predictive tests, the final validation of countermeasures for space motion sickness, especially those using training techniques, will require a series of controlled studies with individuals who fly on Space Shuttle missions.

In the future, studies should consider the possible consequences of very long duration exposure to null gravity. This issue involves potential irreversible or very slowly reversing functional and/or anatomical alterations that may occur in the gravity receptors, especially the otolith organs. Such alterations could lead to perceptual illusions, ataxia, dysequilibrium, and motion sickness upon return to one-g. Ground-based studies may shed light on these potential effects. On the basis of previous spaceflight data, it is evident that cardiovascular changes have accrued as a consequence of null-gravity exposure. These changes, collectively referred to as cardiovascular deconditioning, include orthostatic intolerance. decreased exercise capacity, and decreases in circulatory blood volume. They have been observed in all crewmembers on return to the one-g environment, even on some very short missions.

It has been hypothesized that exercise may be a partial countermeasure to cardiovascular deconditioning. The Shuttle crewmembers will have access to two types of exercise devices: a treadmill device and a bungy-cord exerciser. The series of events that occur in the cardiovascular system following crew insertion into null-gravity, during adaptation to null gravity, and following return to one-g are complex and only partly understood. It is evident, however, that fluid is displaced from the lower extremities to the central circulation.[5] It is postulated that a series of reflex and mechanical changes occurs as secondary responses to this headward fluid shift. The most obvious results are a decrease in circulatory blood volume and a decreased tone in the peripheral blood vessels. During and following reentry, the cardiovascular system (which has adapted to the absence of gravity) is subjected to a one-g force. The main concerns center on the ability to maintain adequate blood pressure and cerebral circulation during these periods.

Most near-term research is directed toward preventing orthostatic intolerance during Shuttle reentry through the use of anti-g garments or other treatment regimens. Results from ground-based research suggest that in-flight lower body negative pressure training, fluid and electrolyte supplementation, and/or vasoconstrictive and salt-retaining drug therapy may be effective in preventing the problem.

To understand more fully the mechanisms that occur during cardiovascular deconditioning, a series of spaceflight experiments has been proposed. Studies are planned to measure regional blood flow and volume during the transitional periods from one-g to null gravity and back to one-g. Continuous or rapidly repetitive measurements taken during the early Space Shuttle flights will document the time course of the fluid shifts and the changes in cardiovascular function that accompany them. Invasive studies in animal models will yield detailed information on changes in regional blood flow.

Bone and Muscle Loss

It was demonstrated during the Skylab missions that calcium was lost during flight.[6] The rate of calcium loss did not appear to diminish over nearly 3 months.The calcium is primarily lost from bone. Bone mineral loss may ultimately limit the time humans can endure weightlessness without the possibility of increasing the incidence of bone fracture. Numerous secondary effects of this mineral loss could be of great consequence. The prolonged elevation of serum and urinary calcium levels could give rise to renal disturbances and calculi (kidney stones). Calcium deposition could take place in other organs with harmful effects.

In addition to calcium loss, a substantial degree of muscle atrophy has occurred in space flight. These changes occur in selective muscles of the lower limbs. Of concern with both

muscle and bone loss are the possibilities of permanent structural change and the possibility that repeated exposure to null gravity results in a progressive and irreplaceable bone mineral loss.

Current research on bone and muscle loss is focused on ground-based studies. Prolonged, enforced bedrest is a reasonable null-gravity model for calcium studies in the human. These studies, have made it possible to eliminate several potential countermeasures from further consideration. Current work is focusing upon pharmacologic intervention.

Shuttle-launched space flight experiments will accelerate work on both human and experimental animals. Both invasive and newly developed noninvasive techniques will be used to better understand and, it is hoped, to prevent the calcium loss.

The approach to the muscle loss problem is somewhat different. Animal models can be used to study atrophy in selected muscle groups. Invasive techniques are being used in ground-based studies to understand the biochemical and enzymatic correlates of this atrophy. These studies may lead to an understanding of exercise and perhaps even of antimyopathic agents.

Red Blood Cell Mass

The most significant effect of the space flight environment on the blood and blood-forming tissues of man has been a consistent reduction in the circulating red blood cell mass during all flight intervals. Data from the Skylab flights indicate that the high oxygen level used in earlier vehicles is not the cause. It appears that some other characteristics of the space flight environment causes a suppression of red blood cell production.

Research tasks are directed toward understanding why red blood cell production is suppressed in space flight. Of equal interest are the associated changes in cellular shape, overall metabolism, and membrane function.

Detailed human studies involving serial sampling in flight and detailed analysis on the ground will be performed on Shuttle missions. In addition active experiments involving radioactive tracers and tissue samples, detailed examination and study of bone marrow, spleen, and lymph nodes will be conducted on animal models. Current ground-based work is examining possible models that would be appropriate for such studies.

Fluid and Electrolyte Changes

It has been demonstrated that exposure to weightlessness results in a redistribution of the volume of blood within the vascular system. This redistribution is interpreted as an increase in blood volume by sensory receptors located in the heart, thus initiating a compensatory loss in water, sodium, and potassium from the renal tubules. This loss of water and salt has been manifested during every space flight as a loss in body weight, most of which is rapidly regained postflight.

Associated with the redistribution of fluid is a series of endocrine and hormone changes. A coordinated plan using ground-based and flight experiments has been developed to address the fluid and electrolyte concerns. Because the onset of fluid redistribution occurs immediately upon entry into the null-gravity state, the Spacelab flight experiments are designed to gather data from the earliest moments of weightlessness. In addition to documenting the natural history of the many known responses, attention will be paid to the complex array of secondary hormone and endocrine responses that appear to be initiated.

Reentry G-Forces

It should be noted that previous United States manned spacecraft reentries have been performed in such a manner that the majority of the g-forces were in the X-vector. In past space flights, this meant that during reentry the blood did not have a tendency to pool in the legs. During Shuttle flights, reentry will be made such that the crewmembers will encounter a fairly long-duration exposure (20 minutes) of low-level +1.5 to +1.8 g_z before landing. It is possible that a combination of the cardiovascular deconditioning that occurs fairly early in the null-gravity space flight will result in some of the crewmen or passengers becoming hypotensive during reentry in the Shuttle with a positive g_z stress. As a result of this consideration, it has been decided that during the OFT phase of Shuttle operations all crewmen will wear anti-g suits during reentry.

The NASA is currently conducting a series of bedrest simulations of a 7-day Shuttle mission. In these tests, a centrifuge is used to simulate the reentry gravitational stress profile of the Space Shuttle. The subjects were placed in two groups. One group was exposed to the nominal Shuttle reentry profile (at least as far as gravity is concerned) on the centrifuge and the other group was exposed to the nominal Shuttle reentry profile with an anti-g suit inflated.

Preliminary results of these studies indicate that, with the level of deconditioning produced by bedrest, the subjects may tolerate the 1.5g profile with or without the anti-g suit. However, the anti-g suit does offer protection if the g-loads are increased above 2.5g. Although bedrest remains one of the best simulations of the null-gravity exposure, it is far from perfect. In fact, the cardiovascular changes noted after bedrest are often somewhat different from those noted by those who have experienced null-gravity space flight.

Therefore, it is considered necessary in many instances to conduct critical testing in the operational environment to assure that conclusions drawn are valid.

The NASA is considering the investigation of the physiological effects of anti-g suits during Shuttle reentry. During this test, crewmembers other than the pilot and co-pilot will be used as test subjects. Each subject will serve as his or her own control because the g-tolerance varies greatly between individuals. Each subject would be noninvasively instrumented to permit quantitation of certain vital physiological parameters during Shuttle reentry. The plan calls for monitoring the electrocardiogram, temporal arterial blood flow, brachial artery pressure, and anti-g suit bladder pressures. It is anticipated that the results of this study during the OFT phase of Shuttle operations should answer the question whether or not anti-g suits need be worn during Shuttle reentry.

Radiation Safety

The NASA has had few problems with space radiation exposure in the past. As an example, the average radiation dose for crewmembers on Apollo missions averaged about 0.4 rad.[7] This is approximately equivalent to the cosmic radiation dose experienced by U.S. citizens living at 2000 m altitude for a period of 2 years. Crews on the Skylab missions also received minimal doses of radiation; for example, it is calculated that the Skylab 4 crewmen could fly one 84-day mission a year for 50 years before exceeding their career limits. The NASA career limits during Skylab were 400 rem for blood-forming organs, 1200 rem for skin, and 600 rem for eye lens.

The objective of the JSC Radiological Health Program is to avoid the harmful effects of radiation by limiting the exposure to the lowest possible level. Levels of exposure on the ground are to be consistent with industrial levels controlled by the Nuclear Regulatory Commission, and space radiations affecting the crew and other space workers should be negligible in terms of significant biological effects as defined by the National Academy of Science. To achieve these goals requires constant coordination between the radiological health staff, spacecraft designers, mission planners, and persons exposed to radiation.

Unique aspects of space radiation (high-energy particles) requires that the NASA support a continuing radiobiological research effort in this area. This research is coordinated with other Federal agencies having problems of a similar nature.

Astronauts will encounter a wide variety of ionizing radiations in space. The potential for harmful biological effects from these radiations depends upon the biologically effective dose, which, in turn, depends on numerous factors.

A computer program has been developed which models the expected mission doses from major sources such as the electrons and protons in the trapped radiation belts and their secondary Bremsstrahlung (X-rays) produced in spacecraft components. Other models project the expected doses from solar particle events if some information about the size and characteristics of the event is known shortly after its onset. It is not yet possible to predict the occurrence of a solar particle event, but the probability of one occurring is calculable. Additional models are used for projecting the major fraction of the dose from galactic cosmic radiation for particular missions at particular times in the sunspot cycle.

Because of the uncertainties in the existing models, the radiological health strategy does not rely solely on calculations; onboard dosimetry is also required. Onboard dosimetry is provided for the following reasons: (1) to verify projections, (2) to refine computer models and projections, (3) to obtain accurate dosimetry from unexpected (and poorly modeled) events such as (a) solar particle events, (b) nuclear detonations, (c) accidental releases of radioactive material, which may be used in payload experiments, and (d) leakage of radiation from onboard sources (e.g., radioactive thermoelectric generators, nuclear power reactors, sealed sources used in experiments, radioluminescent devices, etc.).

Not only are dosimeters needed for unexpected events and verification and refinement of modeled dose projections, but they serve as part of the medical record of each astronaut and thus are useful in evaluating the contribution of radiation to any future health problems.

For OFT flights, the expected doses and dose equivalents will be quite low ((less than 10 m rem (1 rem) barring a severe solar particle event)), so use of calculated spectral parameters with minimal onboard dosimetry and conservative assumptions for obtaining a worst-case estimate of dose equivalents will be adequate for radiological health and will not severely affect budgeting of career dose equivalents.

Noise

During the Apollo Program, a special study was implemented by JSC life scientists to evaluate quantitatively the effects of lunar module noise on crew sleep and hearing. During the Skylab Program, life sciences personnel were actively involved in specifying noise limits for the Skylab workshop, monitoring contractor activities pertaining to spacecraft ground-based noise testing, participating in activities involving the actual collection of in-flight noise data, and collecting preflight immediate postflight audiograms on the crewmen on each mission.

On the basis of data previously acquired, it is known that, with a few minor exceptions, the Apollo and especially the Skylab spacecraft internal noise environments were within

acceptable limits. The ambient noise present in these vehicles at no time presented a hazard to the crewmen's hearing and seldom interfered with the crewmen's ability to effectively communicate, perform, and obtain adequate sleep.

Presently estimated Shuttle noise levels, particularly those anticipated for the OFT phase are higher than those specified by NASA. The design limit for Shuttle on-orbit acoustical noise is a noise spectrum equivalent to the NC-50 level.(8) The NC-50 level, which defines a group of octave-band sound-pressure-level limits from 63.5 to 8000 Hz, is the upper limit for spacecraft ambient noise. It is important to understand that the NC-50 level is approximately equivalent to 55 dBA. The A-weighted sound pressure level will always be approximately 5 dB higher than the specified NC level. When dealing with sound that affects humans, the A-weighted level is customarily used because it takes into account the physiological filtering and sound transduction properties of the human ear.

The projected noise levels for the first OFT crew module will be about 82 dBA in the middeck area and 73 dBA on the flight deck. These levels are approximately equivalent to NC-77 and NC-68, respectively. Furthermore, the projected noise spectrum peaks at 2 KHz, which is in the most sensitive region of the human auditory system. The noise levels projected for the Shuttle OFT missions have a definite potential for causing detrimental physiological effects on at least some crewmen.

Using the best available sources of information, it has been determined that continuous exposure to noise levels greater than 76 dBA for periods longer than 24 to 48 hours could cause permanent damage in some individuals. Thus, 82-dBA level projected for the Orbiter middeck area represents a problem.

To reduce the Shuttle OFT on-orbit noise to acceptable levels, several actions are being pursued. These include the design and fabrication of foam-lined equipment mufflers that could be installed in the vehicle before the first OFT mission, the use of sound-attenuating material in the sleep compartment curtains, and the covering of openings in the avionics bay and other areas with easily removed noise-attenuating "patches."

All these engineering fixes to the vehicle hardware are very highly desirable and every reasonable effort is being made to implement these corrective measures. They are much preferred as compared to requiring the crewmembers to wear some type of hearing protection device (eg., earplugs or muffs). Hearing protectors, even if properly fitted, can after a period of prolonged use become a source of discomfort and may, if improperly designed, interfere with the receipt of important auditory information.

Shuttle Atmosphere

The Orbiter and the Spacelab will have a 10.1×10^4 N/m^2 (14.7 psia) environment with two-gas control.(9) In this regard, it will more closely approach a sea-level laboratory environment than prior U.S. spacecraft. The life scientists specified a two-gas Earth-pressure environment particularly for the medical experiments. Engineering considerations also favored an Earth-normal environment. Pressure affects the heat capacity and viscosity of gases and thereby affects the performance of fans in the environmental control system and the cooling requirements of electronics in general.

Oxygen partial pressure in both the Orbiter and the Spacelab will be 22×10^3 N/m^2 $\pm$ 17.2×10^2 N/m^2 (3.2 $\pm$ 0.25 psia), a variation considerably greater than that due to changes in atmospheric pressure at a sea-level laboratory but providing a higher oxygen level than laboratories at higher altitudes.

The carbon dioxide partial pressure requirement for Shuttle is 0 to 1.013×10^3 N/m^2 (0 to 7.6 mm Hg) with a nominal value of 6.6×10^2 N/m^2 (5 mm Hg) stated as nominal for the Spacelab. This level is consistent with levels on prior spacecraft.

The temperature within the Shuttle will be selected by thermostat $\pm$1.1 K (2^o F) within a range of 291 to 300 K (65^o to 80^o F). Temperature control has been acceptable on prior spacecraft. However, the Shuttle temperature control will represent an improvement and will compare well with the temperature control of any well-designed air-conditioned office building or general-purpose laboratory. The selectability of temperature in Spacelab will allow optimization of the temperature environment and may be used to provide reliable $\pm$1.1 K (2^o F) controlled conditions within 291 to 300 K (65^o to 80^o F) range for specific experiments.

The permissible humidity ranges are 8.0 to 10^2 N/m^2 to 18.6×10^2 N/m^2 partial pressure of water (6 to 14 mm Hg)for the Orbiter and 9.3×10^2 N/m^2 partial pressure of water (7 mm Hg) to 70 percent relative humidity for Spacelab. The humidity will not be directly controllable.

The air motion requirements for Shuttle are 8 m/min (25 ft/min) and within a range of 5 to 12 m/min (15 to 40 ft/min). The absence of free convection in null gravity imposes a change in the environment that is not spacecraft controlled. The minimum air motion will provide forced air motion near that provided by free convection.

Extravehicular Activity

Because of experience with extravehicular activity and the usefulness of EVA, this capability has been retained in the Space Shuttle Program and refers to activities for which

crewmembers don their space suits and life support systems and then exit the Orbiter cabin to perform operations inside or outside the payload bay. EVA may be categorized as follows: planned before launch; unscheduled; and contingency, required to effect the safe return of all crewmembers. Current planning calls for each Orbiter mission to provide the equipment and consumables required for three two-man EVA operations, each lasting a maximum of 6 hours.(10)

The airlock provides the means of transfer from the shirt-sleeve environment of the cabin to the vacuum environment of space and contains the pressurization and depressurization systems necessary to effect such a transition. The airlock is removable and can be installed in one of three different Orbiter locations, depending upon the payload. The basic airlock location is inside the middeck compartment to permit maximum use of the payload bay volume. An extravehicular mobility unit, consisting of a self-contained life support system, provides a breathing environment at a pressure of 2.76×10^4 N/m^2 (4 psia) and incorporates provisions for internal liquid cooling, communicates equipment, special EVA helmet visor protection, and external restraint and tethering fittings.

Extravehicular activity must be preceded by an uninterrupted 3-hour period of prebreathing pure oxygen. Prebreathing pure oxygen for 3 hours is required to assure denitrogenation before operating in a 100 percent oxygen environment at reduced atmospheric pressure. For example, if no prebreathing period were included before the EVA, the occurrence of serious bends would be approximately 30 percent depending upon the individual and the EVA work level. It is also essential that the prebreathing period be uninterrupted; that is, that the subject continue to breathe 100 percent oxygen. For example, a 1-minute break close to the 3-hour mark in the prebreathing cycle would require a 30-minute "payback" time such that egress would not occur until 3 hours and 30 minutes had elapsed. However, normal crew procedures anticipate about 15 minutes from donning of the helmet to depressurization. If the suit purge began at the 3-hour mark, a total of 30 minutes (i.e., an additional 15 minutes) would be required before depressurization. It should be noted that complete prevention of the incidence of bends in an unselected population during an operational depressurization from $10.1 \pm 0.1 \times 10^4$ N/m^2 (14.7 $\pm$0.2 psi) cabin atmosphere to a $2.76 \pm 0.1 \times 10^4$ N/m^2 (4.0 $\pm$0.2 psi) suit environment would require prebreathing times of from 10 to 12 hours. The 3-hour value that was established as a Shuttle specification assumes that the crew will be relatively bends resistant. The factors that lead to being resistant to bends include having a low fat to lean body mass ratio, being in good physical condition, and remaining free of bends symptoms during altitude chamber training. It is further assumed that EVA metabolic rates will not exceed the moderate levels experienced during Apollo missions. The 3-hour prebreathing period that is scheduled for Shuttle EVA provides a 95 percent confidence level.

The following typical EVA tasks demonstate the range of EVA opportunities available on Shuttle:

Inspection, photography, and the possible manual override of vehicle and payload systems, mechanisms, and components

Installation, removal, or transfer of film cassettes, material samples, protective covers, instrumentation, or launch and reentry tiedowns

Operation of equipment, including tools, cameras, and cleaning devices

Cleaning of optical surfaces

Connection, disconnection, and stowage of fluid and electrical umbilicals

Repair, replacement, and calibration of modular equipment and instrumentation on spacecraft or payloads

Deployment, retraction, or repositioning of antennas, booms, and solar panels

Attachment and release of crew equipment restraints

Performance of experiments

Cargo transfer

With the manned maneuvering unit, a propulsive backpack device, an EVA crewman can reach areas beyond the payload bay which he could not reach otherwise. The unit, a modular device stowed in the payload bay and readily attached to the extravehicular mobility unit, can be donned, doffed, and serviced by a single crewmember as needed during the EVA period. Because the manned maneuvering unit has 6-degree-of-freedom control authority, an automatic altitude-hold capability, and electrical outlets for such ancillary equipment as power tools, a portable light, cameras, and instrument-monitoring devices; the unit is quite versatile and adaptable to many payload task requirements.

Toxicology

Space toxicology focuses on ensuring that the space crew is not exposed to any toxic hazards while on a mission. The major areas of concern are the accumulation of toxic substances that are emitted in trace levels by various substances in the spacecraft, and ingestion of toxic substances contained in the drinking water system. In practice measures used to ensure crew toxicology protection are preventive in nature. A spacecraft material selection

program has been established for the purpose of reducing the quantity of nonmetallic materials acceptable for space flight, particularly those that could be serious offgassing sources. Material selection programs are conducted on both the Orbiter and the Spacelab. Requirements for the programs are contained in NASA Handbook 8060.1A "Flammability, Odor, and Offgassing Requirements and Test Procedures for Materials in Environments that Support Combustion." Materials that fail these requirements are still needed for space flight use and are handled individually under a provision known as materials-usage agreements. This provision allows a closer toxicological assessment of a given material.

The NASA Toxicology Laboratory is provided with a sample of the candidate material and a thorough analysis of its toxic products is performed. Near the completion of the Shuttle Orbiter, a special offgassing test is performed in which all onboard equipment is brought to operating temperature and a special measurement of the offgassing of the spacecraft materials is completed. During these offgassing tests, the Orbiter cabin is closed so that no exchange of air is permitted with the outside atmosphere. All possible heat-producing equipment is energized before the beginning of the test period. The test is conducted with a maximal amount of flight equipment onboard the vehicle. The Shuttle life support system or environmental control system is activated during a portion of the test.

In addition to special materials testing and full testing for the Shuttle, the NASA Toxicology Program provides the maximum permitted concentration levels of contaminant gas for Orbiter design. The environmental control system contains a lithium hydroxide canister for the control and scrubbing of carbon dioxide from the cabin atmosphere. In addition, a catalytic oxidizer has been added to the environmental control system for the removal of carbon monoxide.

Special consideration is given to the compressed and cryogenic breathing gas supplies flown on the Shuttle. These gases are screened to assure that they do not contain excessive levels of trace contaminants.

Contaminant gases produced by pyrolysis or combustion of nonmetallic materials is very difficult to predict. If a problem on the Shuttle develops in which a fire is suspected, the crew immediately dons a mask that provides access to protected contaminant-free breathing gas.

During space flight, gas samples will be taken at the beginning, middle, and end of the mission. The absorbent trapped samples will be collected in flight and analyzed on return to the Earth. In later missions, the Space Shuttle may carry a trace gas analyzer that will provide real-time information concerning onboard trace contaminant gases. Common component trace gases found in spacecraft environments include acetone, ammonia, benzene, butyl alcohol, and carbon monoxide.

Food and Nutrition

Initially, concern existed for the mechanics of eating and eliminating in weightless flight. The space flight experience of American and Soviet pilots largely has dispelled these fears. Indeed , their observations validated the previous findings of aircraft experimenters flying parabolic maneuvers; that is, that physiological mechanisms of food ingestion are not very sensitive to gravity. Although the absence of gravity restricted the choice of some foods and constrained the design of packages, once food was in the mouth, the subsequent steps of swallowing, digestion, and elimination appear to proceed in a normal fashion. The Skylab crews performed a control study to determine whether any changes in the physiological response to taste or aroma occurred during weightless flight. These tests provided no indication or evidence of any change in the ability to identify aromas. Furthermore, no evidence in any of these data suggested that weightlessness is a significant factor influencing the flavor of food.

A determination of energy requirements is crucial to the design of life support systems and to overall assessment of man's ability to live in weightlessness. It might seem logical to assume that activity in weightlessness would require less energy than in one-g because the counteracting force of gravity would be eliminated. Although locomotion in reduced and null gravity requires less energy than at one-g, those tasks that ordinarily depend on friction for their reactive force require muscular work to supply that force. In addition, very little of man's basal energy expenditure is attributable to direct gravity effects. Examination of data acquired during the Skylab missions reveals that the overall energy consumption in flight is not statistically different from that observed on the ground.

On Skylab, each of the 70 or so individual foods that were provided was analyzed for all known nutrients, including individual amino and fatty acids. Carbohydrate consumption was generally higher in flight than on the ground with averages of 400 grams per day and 350 grams per day, respectively. Fat intake in flight was lower on an isocaloric basis. Crude fiber intakes were about 5 to 10 grams per day in flight and on the ground. Based on experience with previous space flights, the Shuttle food system is designed to provide crew nutritional energy requirements for good health and effective performance. To maintain good nutrition, each crewmember should consume at least the following quantities of nutrients each day.[11]

Protein	(g)	56	Vitamin B_{12}	(µg)	3.0
Vitamin A	(iu)	5000	Calcium	(mg)	800
Vitamin D	(iu)	400	Phosphorus	(mg)	800
Vitamin E	(iu)	15	Iodine	(µg)	130
Ascorbic Acid	(mg)	45	Iron	(mg)	18

Folacin	(μg)	400	Magnesium	(mg)	350
Niacin	(mg)	18	Zinc	(mg)	15
Riboflavin	(mg)	1.6	Potassium	(meq)	70
Thiamin	(mg)	1.4	Sodium	(meq)	150
Vitamin B_6	(mg)	2.0			

Diets will be based on a variety of common foods to provide other nutrients for which human requirements have not been well defined. Current planning stipulates that 3000 kilocalories per day will be provided. However, the total energy content of the diet will be predicted upon an accurate estimate of each crewmember's lean body mass in accordance with formulas for energy utilization in weightlessness. The constituents of the Shuttle food will be known quantitatively. The various sources from which the NASA obtains these data include manufacturers' specifications, the U.S. Department of Agriculture, and the Food and Drug Administration, and in some cases based on special tests.

Health Stabilization for Orbital Flight Tests

The purpose of the Health Stabilization Program for the OFT missions is to maintain the health of the crewmen during the critical period just before launch. The objective of the program is to minimize and to preclude, if possible, exposures to infectious diseases for all flight personnel. The Health Stabilization Program will be made operational during a 7-day period immediately preceding launch of each OFT mission.

A reduction in the number of isolation days from earlier missions is the approach for the OFT phase. On past mission, 80 to 85 percent of the illnesses reported by primary contacts were upper respiratory illnesses. The incubation for most of these illnesses range from 3 to 5 days. With a 7-day isolation period, this type of illness can be detected in the crewmen before launch. Further exposures to upper respiratory infection, which could cause in-flight crew illness, can be prevented.

The excellent results obtained with this program on past missions attest to the fact that the individual efforts by primary contacts and crewmen have been outstanding. Since the program was initiated, an infectious illness has not occurred in any crewmen during the time of coverage.

It is expected that the Health Stabilization Program as presently defined will not be routinely implemented subsequent to the OFT phase. Specific operational Shuttle missions may be defined for which it will be necessary to provide some form of health stabilization. As such missions become better defined, the required plans will be developed to support such flights. To assure appropriate health stabilization measures for the operational Shuttle Era, the Space and Life Sciences Directorate of the Johnson Space Center has established and will maintain a committee to determine the need for health stabilization for each flight.

Shuttle Biowaste

Spaceflight waste management systems have progressed from the simple bag collection systems flown in Mercury, Gemini, and Apollo to the relatively sophisticated systems used in Skylab and planned for use on Shuttle. The Shuttle biowaste collection system provides for the collection of urine and feces and for disposal. This biowaste system can process waste from both males and females as well as process waste water from the personal hygiene station and from the portable life support system.[12] The system is located in a privacy compartment on the middeck of the Shuttle Orbiter.

The Shuttle biowaste system can be used in a standing or sitting position. The urine is conveyed into the system and the liquid-air mixture is separated by a centrifugal separator from which the air is pumped out of the unit through an odor and bacteria filter. The urine flows from the separator to the waste water tank.

The system configuration provides for combined micturation and defication. In this process the user positions himself on the seat using the seat and foot restraints. The urine is processed as previously described. The feces and tissue used in cleaning are conveyed into the waste management system by way of air flow. The solid wastes are accelerated into a rotating slinger, where the feces adheres to the inner wall in a thin layer around the periphery. The transport air flow exits the commode by way of a bacteria filter at the base. Completion of this process is followed by a semi-automatic water flush for cross-contamination control.

Work/Rest Cycles

Flight planning for Shuttle space flights includes the details of the work/rest cycles. Nominally eight hours will be set aside for sleep and 16 hours for activity, which includes time to eat, work, and rest or excercise. Some Shuttle missions may require two-shift operation.[13] Two-shift operation onboard Shuttle could present some problems in that the rest cycle for some crewmen may be interrupted by the activity cycle for the other crewmembers. For the two-cycle mode of operation the Shuttle sleep stations will be configured so that they limit extraneous noises and light.

For the two-shift mode of operation it will be necessary to interrupt and change the circadian rhythm pattern of some of the crewmen during the mission. During launch the crewmen will be on a standard work/rest cycle. It is anticipated that subsequent to launch these

cycles will have to be adjusted fairly rapidly so that the two-shift operation may be accommodated on board. Prior to return it will be necessary for another adjustment to return to a single-shift operation just prior to reentry.

Crew Health Maintenance

NASA medical personnel are responsible for the health of all persons flying in NASA spacecraft. This includes the application of principles of preventive medicine as well as the treatment of any illnesses or injuries which may occur as a result of space flight. All personnel who fly on NASA spacecraft must hold a current NASA medical certification. The following classifications are currently in use: Class I for pilot astronauts, Class II for mission specialists astronauts, and Class III for payload specialists. During the orbital flight phase each crewman will have four preflight examinations. These evaluations will start 30 days prior to the flight and will be concluded on launch morning. The protocols for these preflight medical evaluations include a dental exam, a medical history, a physical, and laboratory and stress tests.

During the orbital test flight phase there is a Health Stabilization Program which is designed to maintain the health of mission crewmen during critical mission time periods. The objective of the program is to minimize and to exclude, if possible, infectious disease exposures to all flight personnel. The program will be operational during a 7-day period immediately preceding the launch of each Orbiter Flight Test.[14]

Inflight medical support involves trained personnel who have access to the onboard medical kit. One of the crewmembers onboard will be responsible for the onboard medical kit and will be able to communicate with a physician in mission control who in turn has access to a variety of medical consultants. The Shuttle Orbiter medical kit weighs approximately 9 pounds and includes those items which are necessary to treat most minor illnesses and injuries.

Several postflight medical evaluations will be conducted on each crewmember. The first examination will be conducted within 12 hours after landing. The postflight medical examinations include a medical debriefing, a physical examination, and laboratory examination. The returning crewmen may fly in high performance aircraft as a passenger only after certification by the crew surgeon. They may fly as pilot in command of an aircraft after successful completion of an instructor pilot checkout.

The orbital flight test phase of Space Shuttle operations will require the mobilization of an emergency medical service system in support of launch and landing operations. Emergency medical services will be provided to respond to the individual crewmember's need for immediate medical care. If required, the crewmember will have access to a comprehensive inpatient medical care facility capable of treating injuries or illnesses. One of the key elements of the emergency medical services system is a communications capability linking all members of the system.

CONCLUSION

The Space Shuttle has been designed to provide the crewmembers with a safe and comfortable environment in which to work and rest. Past space flight experience has shown that with the proper life support systems man can live and work in the null-gravity environment of space for many days without serious physiological degradation. The physiological changes that the Shuttle crewmembers will experience are, for the most part, predictable and in some cases there are corrective measures which may be taken. Based on previous space flight experience, and given the characteristics of the Space Shuttle, the anticipated physiological changes should not give rise to any serious problems or any long-term irreversible effects.

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DISCUSSION

E. Burchard — Would you comment on the sound level during the launch period? And is the food system going to be comparable to that which you had during the Sky Lab mission?

S. Pool — The noise level during launch will be quite high. However, there will be only transitory peaks and we don't expect any long term loss of hearing as a result of the launch noise. We are concerned about confining people for 24 hours a day in an environment with an exposure to up to approximately 65 decibels. We are working to decrease that level as much as possible. We had, as you know, a rather elaborate food system for the Sky Lab series of flights. In the early Shuttle missions the food system will not be quite so elaborate. The shuttle food system is designed for shorter missions. We have a six or seven day cycle of food service which is repetitive, so if you go into space for 14 days, each Monday you are likely to eat the same meal.

K. Klein — Will you comment on the work/rest cycles and circadian rhythms.

S. Pool — Just about every person who has flown in space has had some difficulty with sleep. That probably is due to a variety of factors: a new and a somewhat threatening environment; perhaps motion sickness; decreased food intake; an overly cold environment (especially in our Apollo flights). But usually after three or four days in this environment the astronauts have slept normally. If we add to that a two-shift operation, we expect additional problems. An added difficulty will be encountered trying to get the crew back on the same cycle for re-entry.

R. Murray — At lunch I overheard some people saying they thought little old grandmothers with tennis shoes were going to ride the Space Shuttle as Payload Specialists and now we hear they are all going to be astronauts. What happened to the little old grandmothers?

S. Pool — Well, there are several who remain as candidates and some will probably make it, but very likely not during the early flights. We have lowered the so-called class three standards for Payload Specialists to what we consider minimal standards, and I think that as we become more experienced, we will be accepting people with some medical deficiencies for space flight.

D. Root — You mentioned that the noise level would be in the neighborhood of 65 decibels. I was wondering where all this noise comes from?

S. Pool — It comes from fans, pumps, heaters, exchangers, some of the avionics and other sources. Unfortunately, they have a tendency to be turned on during orbit and and not just during launch and recovery. Unfortunately, also, they tend to be greater at the mid-deck where people sleep, which is noisier than the upper deck where they work.

J. Heller — I understand you to say that the extravehicular activity (EVA) suits, would be only pressurized to the 4 p.s.i. level. This would be a change from the Apollo suit which was a 5 p.s.i. suit.

S. Pool — We did suit integrity checks on Apollo which went to 5.5 p.s.i. We will go to 5.5 p.s.i. on suit integrity checks on the Space Shuttle also, although the normal pressure at which we operate is around 4-4.2 p.s.i. We have sometimes run EVA's at 3.8 p.s.i.

J. Heller — Would the personnel involved in EVA be denitroginated in the suit or by mask?

S. Pool — The denitrogination process takes a minimum of three hours for a well-conditioned man, and for a female with higher relative body fat content it is going to take longer. We expect a 6% risk of stage I bends even with that preparation. The wash out process is as follows: a mask is worn for the first two hours and 20 minutes; they then enter the air lock and don the suit, which is technically difficult to do. We have recently done some engineering studies trying to see whether or not it is possible to operate the air lock at 100% oxygen. If we can do that, we can probably purge the air lock with oxygen and don the suit without the hazard of interrupting pressure breathing.

LE TRANSPORT AERIEN SUPERSONIQUE
ASPECTS MEDICO-PHYSIOLOGIQUES

par

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S O M M A I R E

Les problèmes médico-physiologiques posés par le transport aérien supersonique ont été étudiés de 1964 à 1974 par deux sous-groupes médicaux l'un français, l'autre britannique. Tous les problèmes ont été abordés par des commissions de spécialistes réunissant médecins, physiciens, chimistes et ingénieurs. C'est ainsi que les pertes de pressurisation, l'ozone, les radiations ionisantes, la climatisation, le bruit, les problèmes visuels, la pollution ont fait l'objet d'études très poussées. Des solutions très satisfaisantes ont été trouvées. Dans certains cas, on a pu prouver, notamment pour l'ozone et les radiations cosmiques qu'ils s'agissaient de faux problèmes et que le vol supersonique à 17 000 mètres n'offrait aucun danger. Compte tenu de tous ces résultats favorables le Concorde a pu facilement obtenir l'autorisation de vol nécessaire.

En juin 1961, un bombardier quadriréacteur B 58 triplace se présentait au Salon de l'Aéronautique au Bourget après un vol de 6 h 15 à partir de sa base de Carswel au Texas. Ce fut un évènement considérable et pourtant un an plus tard les administrations françaises et britanniques envisagèrent la construction en commun d'un avion de transport supersonique capable de transporter à des vitesses identiques une centaine de passagers.

Tout de suite les ingénieurs firent appel aux médecins pour étudier les problèmes nouveaux susceptibles d'être posés par la vitesse supérieure à mach 2 et par l'altitude de croisière d'environ 17 000 mètres. C'est ainsi que le groupe opération français et le project office recommandèrent la formation d'un sous-groupe médical dont la mission fut ainsi définie :

"Le rôle de ce sous-groupe est de faire des recommandations et de fournir des avis sur la physiologie, la psychologie et les problèmes médicaux en général, y compris les études nécessaires pouvant avoir un effet sur la construction ou l'exploitation du Concorde".

La première réunion de ce sous-groupe médical franco-britannique se tint le 24 avril 1964 et pendant 10 ans les réunions furent semestrielles, tantôt à Paris, tantôt à Londres.

Pendant la même période, les américains furent tenus au courant de toutes ces études, puisque tous les ans se tenaient des réunions tripartites dites FAUSST meetings (franco-anglo-U.S. - supersonic transport meetings).

Il fallut d'abord dresser un inventaire complet des problèmes médico-physiologiques du transport supersonique. Certes des avions militaires avaient déjà les mêmes performances, mais leurs conceptions étaient absolument différentes. On s'aperçut alors que nombre d'entre eux n'avaient fait l'objet que de rares études ou même n'avaient pas été étudiés du tout. C'est ainsi, à titre d'exemple, que les radiations ionisantes à l'altitude de 17 000 mètres n'avaient jamais fait l'objet d'expérimentation et que les publications médicales sur ce sujet procédaient par extrapolation des mesures faites à 30 000 mètres et à 10 000 mètres. On ne savait donc pas où aboutiraient ces études et Concorde risquait à tout moment de voir sa carrière définitivement compromise.

C'est ainsi que pendant 10 ans, médecins et chercheurs français et britanniques se penchèrent sur ces problèmes confrontant et discutant régulièrement leurs résultats. Ce n'est pas par hasard que la vitesse de cet avion fut fixée à mach 2,2. En effet à cette vitesse, l'échauffement aéro-dynamique des parois de l'avion atteint 153°C pour le nez de Concorde et 130°C pour le bord d'attaque de l'aile. Si l'on songe qu'en subsonique la température est de - 56°, il existe donc une variation de température de l'ordre de 200°C. Les alliages d'aluminium utilisés par les avions de chasse tels que les "MIRAGE" sont assez fiables pour supporter la répétition de telles variations. Si l'on veut dépasser la vitesse mach 2,2 la température de la peau de l'avion augmente considérablement et il faut utiliser obligatoirement d'autres métaux, tels l'acier qui est beaucoup trop lourd ou le titane, dont la métallurgie est très coûteuse.

PRESSURISATION

A l'altitude de 17 000 mètres, la pression barométrique n'est plus que de 66 millimètres de mercrure et la protection du personnel est indispensable.

.../

L'altitude de pressurisation de la cabine fut l'objet de vives discussions entre médecins et ingénieurs dont les points de vue étaient opposés. Pour les physiologistes l'altitude fictive idéale se situe vers 1 500 mètres, puisque c'est le seuil de déclenchement des mécanismes d'adaptation à l'altitude, entraînant une certaine fatigue ainsi qu'un ralentissement des réactions psychomotrices. Pour les ingénieurs le poids des compresseurs risquait de pénaliser fortement le Concorde parrapport aux subsoniques dont l'altitude fictive est de 2 200 mètres. Finalement une solution de compromis fixant l'altitude de pressurisation de la cabine en croisière de 1 500 à 1 800 mètres fut adoptée.

Dès lors furent étudiées de très près les conséquences d'une décompression rapide. C'est en 1955 que Violette a établi que dans une décompression deux facteurs interviennent :

1. le coéfficient de fuite (c'est à dire le rapport surface de l'orifice de fuite/volume de la cabine)
2. le rapport pression initial/pression finale.

Certes le volume de la cabine du Concorde est beaucoup plus important que celui des avions militaires, aussi tous les efforts des ingénieurs se portèrent-ils sur la solidité de la cabine dont la rupture devait être aussi improbable que la perte d'une aile pour un avion subsonique. Une nouvelle technique d'usinage dans la masse a permis la suppression des rivets. La surface des hublots fut réduite à environ 150 cm2, enfin la visière en vol supersonique a assuré une protection accrue du pare-brise.

La règlementation qui a été retenue (T.S.S.7,1) concernant la pressurisation est plus précise et plus sévère que celle qui est appliquée aux avions subsoniques :

"En condition de vol normal et après toute panne fréquente, probabilité (10 - 3) l'altitude cabine ne doit pas dépasser 8 000 pieds.

"L'altitude cabine devra rester inférieure à 15 000 pieds après toute panne peu fréquente (c'est à dire de probabilité comprise entre 10 - 3 et 10 - 5). Après l'application de la procédure de secours, il sera possible de ramener la pression cabine à une valeur inférieure à 8 000 pieds.

"L'altitude cabine devra rester inférieure à 25 000 pieds après une panne rare (c'est à dire de probabilité comprise entre 10 - 5 et 10 - 7).

"L'altitude cabine ne pourra être supérieure à 25 000 pieds qu'en cas de panne extrêmement rare, c'est à dire de probabilité inférieure ou égale à 10 - 7."

Par souci de sécurité sur Concorde il existe deux systèmes indépendants de pressurisation. En cas de panne de l'un des deux systèmes signalés par une alarme, le second système est mis en oeuvre manuellement.

Les équipages des avions militaires supersoniques utilisent à hautes altitudes des systèmes individuels de protection, tels les vêtements pressurisés. Naturellement cette solution ne pouvait être retenue pour les équipages des avions commerciaux. Une surpression automatique est à la disposition du P.N.T., qui est ainsi "couvert" jusqu'à l'altitude cabine de 45 000 pieds. Les masques à oxygène prévus pour l'équipage technique doivent être d'une utilisation aisée. Ils doivent pouvoir être mis en place d'une main en moins de 5 secondes. De plus le P.N.T. subit un entraînement à la respiration d'oxygène en surpression afin dans des cas exceptionnels de pouvoir ramener l'avion à une altitude convenable.

Des masques à oxygène sont présentés automatiquement aux passagers et au personnel de cabine à partir d'une altitude de 14 000 Pieds.

Enfin des équipements portatifs sont prévus pour le Personnel Navigant Commercial avec une autonomie de 30 minutes (120 litres minimum). De plus, un équipement thérapeutique, capable d'assurer le traitement simultané de 2 personnes est prévu. Cet équipement doit être suffisant pour 2 % des passagers.

OZONE

L'ozone atmosphérique (03) résulte de l'action des rayons ultraviolets sur l'oxygène.

A partir de 50 000 pieds, l'ozone atmosphérique augmente, passe par une concentration maximale à 90 000 pieds puis diminue en raison de la raréfaction de l'air. Aux altitudes opérationnelles du Concorde on pouvait se demander si l'air comprimé pour l'amener à la pression nécessaire au point du vue physiologique n'allait pas donner des concentrations d'ozone très toxiques. Car l'ozone est très toxique et cette toxicité est liée à sa puissante propriété oxydante. Son action est essentiellement locale. C'est un irritant puissant des yeux, des muqueuses et du tractus respiratoire. Pour les travailleurs, la concentration maximale admissible est fixée à 0,1 ppmv pour 40 heures de travail pendant 5 jours.

La toxicité de l'ozone à de faibles concentrations était très mal connue et a fait l'objet d'études très précises de la part du Professeur BIGET.

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Cependant l'homme tolère des concentrations beaucoup plus élevées pendant de longues périodes dans son environnement au sol. C'est ainsi que des "proportions d'oxydant dans le "smog" de Los Angeles, dont 03 est un élément majeur, a parfois atteint des valeurs d'environ 1 ppmv, sans que l'on puisse observer d'effets parmi la population".

Mais l'ozone est heureusement un corps très instable qui se réduit facilement en oxygène moléculaire par catalyseurs ou par une température élevée = 50 % de l'ozone de l'air est dissocié à 300°C et 100 % à 400° pendant une exposition d'une demi-seconde. L'air passant dans les compresseurs atteignent une température de 600°, on pouvait prévoir qu'il n'y aurait pas d'ozone dans la cabine.

Toutefois des vérifications expérimentales ont été réalisées tant du côté français (Biget) que du côté anglais et ont montré la justesse de ces prévisions.

A la suite d'un accord tripartite entre la Grande Bretagne, la France et les Etats-Unis J.F. Leach et J.F. Sandals ont mis au point en avril 1978 un système d'échantillonnage sur la ligne commerciale entre Londres et Washington. L'air extérieur peut être mesuré à l'aide d'une sonde traversant un faux hublot. Le degré de dégradation de l'ozone dans la cabine peut ainsi être comparé à celui de l'air extérieur. Deux méthodes de mesure furent utilisées, un détecteur Dasibi et un détecteur AID 560. Durant la phase de croisière à 50 000 pieds et à mach 2, le niveau d'ozone de 1,5 ppm est dissocié et se situe au niveau du seuil de détection des détecteurs, soit n'excède pas 0,004 ppm.

Durant la phase de descente, donc de réduction des réacteurs la température baisse et la dissociation de l'ozone est réduite pendant une courte période. C'est ainsi que le niveau d'ozone peut atteindre 0,16 ppm pendant 4 minutes.

Toutes ces expériences très précises montrent bien que l'ozone ne présente aucun danger dans les vols supersoniques.

RADIATIONS COSMIQUES

Les radiations cosmiques ont deux origines :

1/ Le rayonnement cosmique galactique primaire qui est constant et forme l'irradiation de fond. Il est formé de particules animées d'une vitesse voisine de la lumière et est très énergétique.

Il se compose : de protons (noyaux d'hydrogène) 90 %
de particules alpha (noyaux d'hélium) 9 %
des électrons
des rayonnements — en très petites quantités
de ions lourds (noyaux de C, O, Fe, Ca, Mg etc....)

Ces ions lourds ont une énergie énorme et un grand pouvoir de pénétration.

Les intéractions des particules primaires avec les atomes de l'atmosphère ou avec les parois de l'avion produisent le rayonnement cosmique secondaire, qui aboutit à une véritable absorption du rayonnement cosmique au fur et à mesure que décroit l'altitude.

Le rayonnement cosmique galactique varie également en fonction de la latitude, le flux est cinq fois plus élevé aux pôles qu'à l'équateur. Ceci est dû au champ magnétique de la terre qui détourne vers les pôles les particules de basses énergies.

2/ Le rayonnement cosmique solaire varie en fonction de l'activité solaire selon un cycle qui passe par un maximum tous les 11 ans.

Après une période d'activité solaire presque minimale (soleil tranquille), survient une période d'activité solaire où l'on observe des éruptions solaires accompagnées du flux de particules très énergétiques.

Ces éruptions solaires se sont manifestées au cours des années :

1956 - 1957 1967 - 1968 1978 - 1979

Fort heureusement ces éruptions solaires sont prévisibles (M. Simon de l'Observatoire de Meudon) et permettent soit de changer le plan de vol, soit de dérouter l'avion.

Les dangers des radiations cosmiques sont bien connus, elles peuvent diminuer la longévité, provoquer l'apparition de cancer ou de leucose et surtout avoir une action génétique. Tous ces dangers ont naturellement été exploités abusivement par les nombreux détracteurs du Concorde.

.../

C'est ainsi qu'un médecin, ancien chef d'un service de recherches de médecine aéronautique a publié et diffusé dans le monde entier un volumineux article dont les conclusions étaient qu'aucune femme enceinte ne pourrait prendre le Concorde sans danger et comme le diagnostic d'une grossesse au début n'est toujours pas évident, cela revenait pratiquement à interdire l'avion supersonique à toute femme. Cet article a fait l'objet d'un examen très attentif des sous-commissions médicales qui ont pu assez facilement refuter les arguments avancés. Une erreur de ce réquisitoire fut de situer l'altitude de croisière de l'avion au-dessus de 20 000 mètres, alors qu'elle est de 17 000 mètres et ne dépasse jamais 18 000. D'autre part ainsi que nous l'avons déjà dit, aucune mesure des radiations cosmiques n'avait été faite à cette altitude. Aussi fut-il décidé de procéder à des mesures précises et c'est ainsi qu'aussi bien en Grande Bretagne qu'en France sur tous les vols des prototypes et des avions de préséries, elles furent entreprises systématiquement.

A Toulouse, à bord du prototype 001sous la coordination du Professeur Delahaye furent installées des émulsions nucléaires (M. Kaiser du Centre d'Etudes Nucléaires de Strasbourg), des films photographiques et des dosimètres radiothermoluminescents au fluorure de lithium. (MM. François et Portal du Centre d'Etudes Atomiques de Fontenay aux Roses), enfin un détecteur Vamega (Colonel Durney du service mixte de sécurité radiologique).

A titre de comparaison des détecteurs identiques étaient placés au sol à Toulouse.

A Filton, à bord du prototype 002, MM. Fuller, Mac Naughton et Wardmann firent des études comparables en utilisant des films photographiques, des émulsions nucléaires, des dosimètres thermoluminescents au fluorure de lithium et des émulsions Ilford.

La multiplicité des méthodes utilisées et des appareillages s'explique par le fait que les mesures devaient être très précises et ne donner lieu à aucune contestation. Les résultats furent très encourageants puisque les chiffres obtenus se situent entre 0,5 et 0,9 millirèmes par heure. Les doses reçues par les passagers dans les avions supersoniques ne sont donc pas différentes de celles reçues dans les avions subsoniques et même de celles du rayonnement naturel du sol, en particulier dans les terrains granitiques.

La règlementation française qui définit la protection contre les radiations ionisantes a été légalisée par le décret 67.228 du 15 mars 1967 :

"Une irradiation annuelle de 5 000 millirèmes est admissible au-dessus de 18 ans, pour une personne directement affectée à des travaux sous rayonnements. Cette irradiation annuelle ne doit pas dépasser 1 500 millirèmes pour les personnes non directement affectées à des travaux sous rayonnements. Enfin pour le public, l'irradiation annuelle ne doit pas dépasser 500 millirèmes". Les données scientifiques et les mesures de radiation effectuées aux niveaux de vol du Concorde ont permis de classer le personnel navigant de cet avion dans la catégorie des travailleurs non directement affectés à des travaux sous rayonnements.

Lorsqu'apparurent les avions de série, Londres Bahreim pour British Airways le 21 janvier 1976 et Paris Caracas pour Air France le 9 avril 1976 la mesure des radiations continua à être effectuée sur tous les vols. C'est le service central de protection contre les radiations ionisantes (Pr Pellerin et Pr Moroni) qui fut chargé à Air France de la surveillance. La règlementation aéronautique internationale oblige de doter chaque avion Concorde d'un radiamètre de bord qui fournit en permanence le débit de dose instantané. Un signal lumineux et sonore avertit lorsque ce débit atteint 10 millirèmes/heure pour la mise en alerte et 50 millirèmes/heure pour la décision de descente (Action level). En outre, un totaliseur fournit la dose totale de rayonnement reçue pendant un vol donné. Ce détecteur est de fabrication anglaise et a été conçu par l'Atomie Weapons Research Establisment (A.W.R.E.).

Pour vérifier ce détecteur et éviter ainsi toute source d'erreur, un dosimètre de principe différent basé sur la thermoluminescence de cristaux de fluorure de lithium et l'utilisation de plaques nucléaires pour les neutrons a été placé à bord de chaque Concorde parle S.C.P.R.I..

La comparaison des deux méthodes de mesure utilisées a donné pour l'année 1976 des chiffres comparables : (Lavernhe, Lafontaine et Laplane) :

- Radiamètre A.W.R.E. = 0,99 millirèmes/heure
- Dosimètre S.C.P.R.I. = 0,96 millirèmes/heure

Le niveau d'alerte de 10 millirèmes/heure n'a jamais été atteint et il n'a jamais été envisagé de modifier le plan de vol de l'appareil.

Toutes ces recherches ont prouvé à l'évidence que les radiations cosmiques ne présentaient pas un danger constant pour les pilotes et les passagers du supersonique.

CLIMATISATION

La climatisation a été étudiée par Lemaire et des expérimentations ont été réalisées par Colin au Centre d'Essais en Vol de Brétigny.

.../

Lorsque le Concorde vole en subsonique, la température extérieure est de - 56°C. Par contre en supersonique l'échauffement aérodynamique des structures externes, par suite du frottement de l'air porte la paroi de l'avion à 130°.

Il se produit alors un transfert de chaleur vers l'air de la cabine. La climatisation a donc fait appel à des méthodes nouvelles. Le confort thermique se situe entre 15°C globe et 30°C globe et la vitesse de l'air doit être inférieure à 36 mètres par minute. En cas de panne très improbable de climatisation il faut savoir qu'une température globe de 50°C peut être tolérée en sécurité pendant 56 minutes.

PROBLEMES VISUELS

Les problèmes visuels ont fait l'objet d'étude par Perdriel et Chevaleraud, en collaboration avec les ingénieurs. Le temps dont dispose le pilote pour inspecter l'espace et prendre des décisions est d'autant plus réduit que la vitesse s'accroit.

En vitesse supersonique il faut un délai de trente secondes pour réaliser une manoeuvre d'évitement efficace.

Si la vitesse de rapprochement entre deux transports supersoniques est de mach 4, la distance parcourue est d'environ 20 miles, mais si on veut faire intervenir un facteur de sécurité de 2, la distance de détection est alors de 40 miles nautiques.

Dès lors il faudrait envisager des feux anti-collisions d'une portée de 100 kms. Seuls les feux blancs peuvent avoir une telle portée, mais ils ne sont pas règlementaires dans l'aviation. De plus ces feux ne doivent absolument pas dépasser la structure de l'avion, ne fut-ce que d'un millimètre, sinon ils éclatent.

Finalement, le Concorde en vitesse supersonique utilise des appariils d'information électronique et en subsonique les feux anti-collisions de couleur rouge retrouvent toute leur valeur.

BRUIT

Des règlements internationaux (OACI - Annexe 16 - 1971) et des règlemeents nationaux fixent les limites de bruit des avions subsoniques qui sont soumis à un contrôle dans des conditions normalisées aux trois points suivants :

L = point latéral au décollage
S = point survolé en montée après décollage
A = point survolé en approche avant l'atterrissage

Les valeurs maximales ont été fixées à 108 EPN dB à chaque point de contrôle avec un total de 324 EPN dB. Une certaine tolérance est admise pourvu que le total soit respecté.

Aucun règlement n'existe pour les avions supersoniques. On ne peut nier que le Concorde fasse du bruit, mais il faut être réaliste et les mesures montrent que des progrès sensibles ont été observés à chaque nouvelle génération d'appareils, appareils prototypes, appareils de présérie et actuellement appareils de série.

Le but était de ne pas dépasser le bruit des avions subsoniques contemporains et on peut dire que cet objectif a été pratiquement atteint.

Voici les comparaisons de mesures de bruit faites entre les Concorde de série et les B 707 et DC 8 :

	L	S	A	TOTAL
Concorde de série :	112,2	119,5	116,5	348,2
B 707 et DC 8 :	108	114	120	342

On est en droit d'espérer que les ingénieurs pourront dans l'avenir apporter encore de notables améliorations.

POLLUTION

C'est un sujet qui a été largement mis en vedette par les adversaires de Concorde.

La pollution de l'air est le fait de l'ensemble des moyens de transport, des usines, des centrales thermiques, électriques etc.... La contribution de Concorde à cette pollution est presque négligable. Dans le cas d'un moteur, la pollution résulte de la combustion incomplète du mélange carburant.

.../

Deux catégories de polluants sont à considérer :

1. Les substances toxiques (CO, NO, SO, hydrocarbures.....)

2. Les substances non toxiques, mais pouvant avoir des effets sur le climat (CO2. H2O particules de carbone).

A égalité de kms parcourus, Concorde n'émet pas plus de polluant que trois automobiles. Une flotte de 330 Concorde en exploitation produira à peu près la quantité de polluants du 1/1000 de la pollution industrielle globale. Pour le même nombre de passagers transportés sur la même distance, Concorde produit dix fois moins de polluants que le nombre de voitures correspondant.

CHARGE DE TRAVAIL ET APTITUDE MEDICALE DU PERSONNEL NAVIGANT

L'augmentation de la vitesse va dans le sens d'une augmentation de la charge de travail des équipages. Dès lors on pouvait se demander si les conditions d'aptitude physique et mentale des pilotes de ligne devaient être révisées. La sélection physique actuelle est suffisante et il n'est pas question de chercher à sélectionner des surhommes. En effet le Concorde est un avion comme les autres.

Pour le passager, la seule différence est la vitesse inscrite sur le machmètre. Pour le pilote et l'équipage, si un certain nombre de procédures sont effectuées en une durée moindre, il ne faut pas oublier que cette augmentation de la charge de travail est compensée par les améliorations technologiques modernes en particulier par les aides automatiques au pilotage et à la navigation (études effectuées par Auffret en collaboration avec la division des Essais en Vol de la SNIAS). Cette affirmation formulée avant l'entrée en service du Concorde a été largement confortée par l'avis des navigants des compagnies utilisatrices de l'appareil. De plus la fatigue des équipages liée aux décalages horaires a pratiquement disparu avec Concorde : en effet un horaire judicieux permet au personnel navigant de revenir dormir à son point de départ.

.*.

Dans ce rapide aperçu des principaux problèmes posés par l'aviation supersonique commerciale, je pense vous avoir montré tout le sérieux avec lequel les études ont été poursuivies. Alors que les avions conventionnels sont livrés aux Compagnies après 1 000 heures de vol, Concorde n'a été mis en service à Air France et à British Airways qu'après 5 000 heures de vol d'essais.

Malgré tout, cet avion a été l'objet de campagnes de dénigrement systématique et même en France.

C'est ainsi que dès 1964 un homme politique français dans un livre qui eut un certain retentissement écrivait "Le Concorde sera la diligence du supersonique". Cette formule bien faite pour frapper les esprits des non initiés s'est avérée complètement fausse.

De même en Août 1972 au Congrès Mondial des consommateurs réuni à Stockholm, le Secrétaire Général des Unions de Consommateurs Français, a demandé que "le boycott du supersonique soit organisé, car les études faites sur la sécurité des passagers, notamment à propos des radiations ont été insuffisantes". On croit rêver en entendant de pareilles contre-vérités....

Arrivé au terme de mon exposé, je voudrais exprimer ma reconnaissance au Docteur Paul Campbell, ancien Directeur des Recherches de l'Ecole de Médecine Aéronautique de l'U.S.A.F. qui après avoir suivi les études françaises et britanniques sur Concorde et avoir participé à quelques vols écrivait le 10 janvier 1976 à M. W.T. Coleman, Ministre des Transports, avant que celui-ci ne prenne la sage décision d'autoriser l'atterrissage de cet avion à Washington :

"In my belief, it is the greatest commercial transport aircraft of aviation history. I see it to have no drawbacks of any type possibly one, it does not belong to rise"

"C'est le plus grand avion de transport commercial de l'histoire de l'aviation. Il n'a aucun défaut, si ce n'est de ne pas avoir été construit par nous".

-.-.-.-.-.-.-

DISCUSSION

F. Violette I have two points to add to General Raboulet's presentation. First, it should be emphasized that the Concorde is the result of close and successful cooperation between the French and British and is a good example of the possibilities of international cooperation. Second, while most airplanes are designed by engineers without much consideration for the passengers, the Concorde was built with close collaboration between engineers and physicians - a plane designed for passengers.

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14. Abstract

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Two papers presented at the meeting of the Aerospace Medical Panel in Brussels, on the 26 January 1979, provide valuable data gained from the experience with the selection and training of Space Shuttle Payload Specialists as well as a review of physiological problems expected during the forthcoming Space Shuttle operation because of the environmental stress of space life.

Three other papers given in this meeting session are intended to update the Aerospace Specialist in the selection of aircrew (including female personnel), basic science concepts and clinical operational requirements of advanced oxygen systems designed for future high-performance combat aircraft and – for the first time at AGARD meetings – medical and physiological problems faced during the development and operation of commercial supersonic vehicles.

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