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ADVANCED TECHNOLOGY ANTI-G SUIT (ATAGS) FABRICATION

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December 1990

Final Report for Period August 1989 - August 1990

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Prepared for
USAF SCHOOL OF AEROSPACE MEDICINE
Human Systems Division (AFSC)
Brooks Air Force Base, TX 78235-5301

NOTICES

This final report was submitted by KRUG Life Sciences, San Antonio Division, 405 W. Nakoma, San Antonio, Texas, under contract F33615-89-C-0603, job order 7930-17-07, with the USAF School of Aerospace Medicine, Human Systems Division, AFSC, Brooks Air Force Base, Texas. Mr. Larry J. Meeker (USAFSAM/VNS) was the Laboratory Project Scientist-in-Charge.

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The voluntary fully informed consent of the subjects used in this research was obtained in accordance with AFR 169-6.

This report has been reviewed and is approved for publication.

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The development and testing of twelve extended coverage G-suits is addressed in this report. These suits were proven superior to the current CSU-13/BP suit at Edwards AFB during flight trials in 1988. Utilizing the comments from the pilots in the 1988 flight trials, the suits discussed in this report improved comfort, donning/doffing and mobility without sacrificing performance. An account of the conceptual, developmental and testing stages of the extended coverage G-suits, i.e., the Advanced Technology Anti-G Suit (ATAGS), is provided.

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CONTENTS

LIST OF FIGURES.

Page

LIST OF TABLES.

ADVANCED TECHNOLOGY ANTI-G SUIT (ATAGS) FABRICATION

1. INTRODUCTION.

Initial design proposals for an extended cover anti-G suit were submitted by KRUG Life Sciences to the USAF School of Aerospace Medicine (USAFSAM) in October 1986. These proposals were subsequently incorporated in a limited number of development garments, designated "Uniform Pressure Anti-G Suits" (U.P.S.), produced under Contract No. F-33615-85-C-4503. Although in an exploratory design form, the U.P.S. was evaluated subjectively in centrifuge tests at USAFSAM and in limited service flight tests at Edwards AFB, CA. From these U.P.S. evaluations, a significant ennancement of subject tolerance to repetitive G exposure was reported (Ref. 1). This finding led to the promulgation, in August 1989, of Task Order No. 0001 of Contract No. F-33615-89-C-0603. Under this Task Order, KRUG Life Sciences further developed the U.P.S., (redesignated the Advanced Technology Anti-G Suit (ATAGS)), and produced 12 garments, to an enhanced design standard, for centrifuge and flight test evaluation.

Based upon comment and criticism from the U.P.S. subjective evaluations, Task Order No. 0001 detailed requirements for the improvement of specified comfort, convenience and operability features in the revised design of the ATAGS. This report gives details of the Task Order objectives and of design, development, production and testing programs undertaken by KRUG Life Sciences in response to those objectives.

2. TASK ORDER OBJECTIVES.

The contractor shall produce 12 ATAG suits incorporating the modifications as specified under the following Description of Work section and any other modifications required for centrifuge and flight test evaluation. The contractor shall support the centrifuge testing of these suits and make further adjustments and modifications of the ATAG suits as defined during testing.

3. TASK ORDER: DESCRIPTION OF WORK.

The contractor shall incorporate into the ATAG suit design the following modifications defined during testing of the U.P.S.:

(a) Improve ease of don/doff procedure by moving zipper to outside.

(b) Incorporate an in-flight relief capability with zipper in crotch.

(c) Increase suit inflation rate by:

(i) Minimizing flow resistance via incorporating a reinforced supply hose and a rubber inlet spout.

(ii) Custom fitting of bladders, especially in the leg, and selecting material for an outer restraining layer with less stretch to reduce suit volume.

(d) Improve comfort in the ankle/foot area.

The intersection of the calf bladder and the top of the foot bladder shall be adjustable.

(e) Improve shape of the abdominal bladder:

(i) Fit the shape of the top of the abdominal bladder to the rib cage.

(ii) Add internal "I" beams to control the shape and reduce the bladder extension.

(f) Add a cooling system and evaluate in a more severe thermal environment.

(g) Incorporate other modifications as defined during testing.

The contractor shall construct a total of 12 ATAG suits suitable for flight test evaluation and deliver them to the USAF. These suits shall be distributed in 8 different sizes. Final size distribution shall be determined by the contractor and approved by the USAF contract monitor prior to start of fabrication. Acceptance of ATAG suits is subject to inspection and approval by the contract monitor in writing 30 days after delivery.

At the conclusion of the task, the contractor shall deliver a final report which summarizes all test results and includes all design calculations, drawings and sketches required to fabricate additional ATAG suits.

Period of Performance: 12 months from mailing date (10 August 1989).

4. TASK ORDER PROGRAM: SUMMARY.

The extensive design changes required to the original U.P.S. to meet the requirements of Task Order No. 0001, necessitated an intensive and prolonged exploratory development period at the beginning of the work program. In the U.P.S. development program, limited attention was paid to the requirement for multi-subject sizing, or to subject/garment sizing relationships. The absence of information pertinent to those areas additionally dictated, at an early stage in the ATAGS program, the need to define and establish a practical garment sizing approach, based on USAF aircrew anthropometric data.

In support of the progressive development and proving of the stipulated ATAGS design improvements, and of the garment sizing approach, a total of 6 ATAGS were required. These suits (01 through 06) were produced by KRUG Life Sciences in the Aircrew Life Support Equipment Development Laboratory at USAFSAM, Brooks AFB, Tx. On completion of ATAGS No. 06, the design standard for garments to be submitted for USAF flight trials, under Task Order No. 0001, was sealed. ATAGS No. 07 through 12 were subsequently produced for flight evaluation. These 6 garments were manufactured to a common basic design (Fig. 1) in 3 sizes to accommodate 18 nominated Edwards AFB flight test subjects.

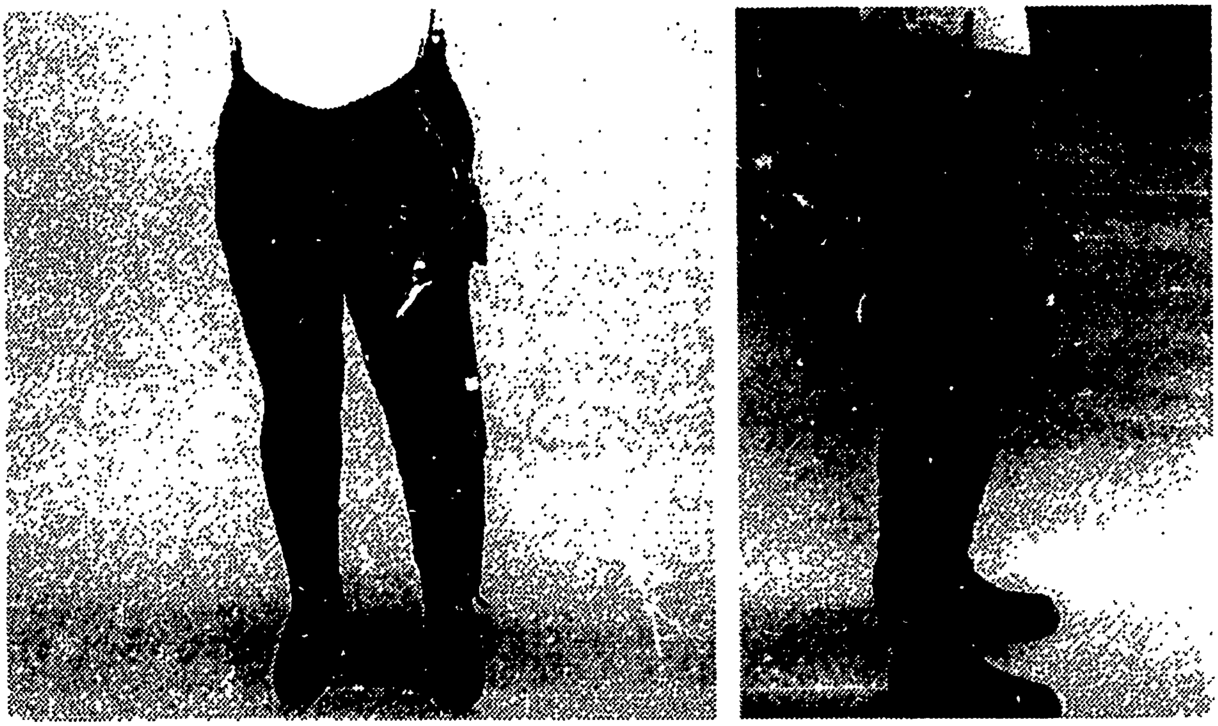

Figure 1. Front and side views of subject wearing final design standard ATAGS fully zipped up.

With USAFSAM contract monitor agreement, the detailed sizing of ATAGS No. 07 through 12 reflects the sizing needs of the discrete flight test subject population. The selected sizes do not necessarily equate exactly to sizes which would be included in a sizing tariff for the USAF aircrew population as a whole. Details of the adopted sizing, and broad recommendations for ATAGS sizing for the aircrew population as a whole, are given in Section 5.2.

From early development, the sizing system applied to the ATAGS was based on an assumption that the development suit would be worn under an aircrew coverall. More recently expressed aircrew opinion, however, has indicated that, to permit maximum flexibility of ATAGS use in its planned flight evaluation, the ATAGS requires the versatility to be compatible with wear under or over the flight coverall. In ATAGS 07 through 12, because of time constraints, the minor dimensional increases ideally required for internal coverall accommodation have not been incorporated. However, in these 6 suits, design features have been incorporated to eliminate the flight safety snagging hazard of exposed suit adjustment lacing if the ATAGS is worn as an external garment.

The final selection of materials and components for incorporation in the prototype ATAGS was to a large extent influenced by existing life support equipment practice. This selection was dictated, primarily, by contract time constraints which imposed limits on the extent to which potential alternative materials and components could be defined, acquired and fully evaluated prior to finalizing the ATAGS design standard. Full details of all materials and components incorporated in the flight standard ATAGS are given in Section 5.4.

During the progressive development of the ATAGS, glued and taped seam construction (Fig. 2) was adopted for the inner gas-holding bladder. This construction technique, which adequately satisfies the bladder pressure-integrity requirements, was used for all contract suits except ATAGS No. 09. In suit No. 09 the use of R.H.F. fabric-welding construction techniques (Fig. 3) was tested in the established ATAGS bladder design. This test was satisfactorily achieved by the subcontractor, M.L. Lifeguard Equipment Ltd.; U.K. Suit No. 09, incorporating this welded bladder, is included in the minimal of 6 ATAGS submitted by KRUG Life Sciences for service flight evaluation. The constructional method of ATAGS No. 09 to the other flight appraisal suits is considered unlikely to significantly influence aircrew appraisal responses.

Figure 2. Glued seam construction, Dutch lacing and abdominal bladder configuration.

During the design evolution stage of the ATAGS development program, a system of "dutch-lacing" was developed (Fig. 2) for linking the ATAGS inner bladder component to the outer restraint layer. This interim linking system permitted the ready interchange and evaluation of contending designs of inner bladder in a single outer restraint garment, to economize program time and effort.

In ATAGS 05 and 08 through 12, however, the "dutch-lacing" method of bladder-to-outer restraint linking was replaced by the more conventional, and production compatible system of direct sewing (Fig. 3). Of the ATAGS produced for flight evaluation, only ATAGS 06 and 07 incorporate the "dutch-lacing" bladder-to-outer linking system.

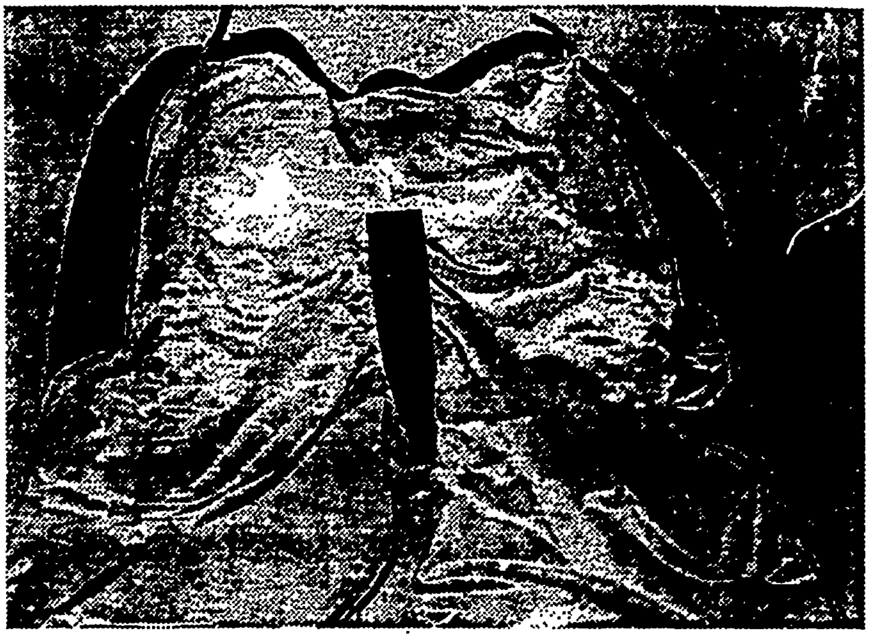

Figure 3. Welded seam construction, sewn-in inner and abdominal bladder configuration.

In satisfying the requirement for the ATAGS to provide full, pressure bladder coverage of the feet and ankles, it was recognized that separable, custom-fitting pressure socks, were needed at base level. To meet this essential need, design and development emphasis was placed on satisfying the requirements for sock sizing, suit-sock coupling, sock donning and maintaining pressure coverage at the sock-suit interface.

In the KRUG developed ATAGS, the area of pressure bladder coverage provided by the garment equates closely with that of the earlier U.P.S. Continuity of bladder coverage is provided in the ATAGS to all suit areas below the waist except at the front crotch, locally at the front groin lines, and at the suit rear above the gluteal fold (Figs. 2, 3). Further investigations to assess the influence of increased or decreased suit bladder coverage on subjective and physiologic acceptability were not attempted due to program time constraints.

At all appropriate stages in the ATAGS development program, laboratory and/or centrifuge testing was undertaken to validate the ATAGS design features, the garment sizing approach, suit construction procedures and completed garment pressure and leakage integrity. Details of the testing program are given in Section 5.5.

As required under the Task Order No. 0001 Objectives and Description of Work, KRUG Life Sciences has produced 12 ATAGS. As stated earlier in this report, with the need to devote 6 of these suits to developmental proving, only 6 suits, which reflect a finalized design standard, were submitted for flight evaluation. By approved concession, the flight evaluation suits have been produced in 3 sizes to fit the nominated flight trial subjects. With the exception of the limited requirements listed below, ATAG Suits 05 through 12 incorporate all of the improved design features specified in the task order. Specific areas of noncompliance with the task order requirements are:

(a) The custom fitting of ATAGS bladders to increase the suit inflation rate was impracticable for multi subject fit garments. Providing adjustment lacing to control suit-girth bulk as well as other modifications to reduce the suit airflow resistance has improved the ATAGS inflation response.

(b) In the early stages of the ATAGS development, attempts to locate and procure suitable alternative restraint layer fabrics with less stretch to reduce suit volume were unsuccessful. This dictated the use of a conventional Nomex fabric in the ATAGS restraint layer. Information was, however, obtained on potentially applicable Kevlar based fabrics, currently under development; details of these fabrics are given in Section 5.4.

(c) Providing a cooling system for the ATAGS, called for in the task order, has not been accomplished. An adequate cooling support system, in the aircraft, is not available and the task of developing a cooling system to meet this need, was determined by government technical personnel to be outside the scope of Task Order No. 0001. Nevertheless, KRUG Life Sciences appreciates the importance of this requirement. Once a suitable air or liquid coolant source has been defined and established, no insurmountable design or integration problems are foreseen in providing a cooling-medium distribution system for ATAGS.

5. TASK ORDER PROGRAM: DETAILS.

Note: The following summarized sub-sections of this report record all the major areas covered in the Task Order No. 0001 ATAGS development program conducted by KRUG Life Sciences. Included in these sub-sections, and associated appendixes, is information defining the design status, testing and flight-worthiness status, and the manufacturing details for the minimal 6 ATAGS suits submitted for flight appraisal.

5.1 Development of Improved Design Features.

As indicated in Section 4, developmental ATAGS 01 through 06 were manufactured to support the progressive development and qualification of the improved design features called for in the task order. These 6 garments were, where convenient and appropriate, also used concurrently for the initial exploration and definition of subject-suit sizing relationships.

To ensure consistency of subjective judgment standards, and experience-based responses in the qualitative assessment of progressive ATAGS design and sizing improvements, the first 6 development garments were sized for a nominated experienced centrifuge-rider at USAFSAM. Confirmation of the single subject findings was, however, when feasible, obtained from specific suit feature assessments by other similarly sized subjects. Details of the development and final status of each significant design feature are given under separate headings. These details include some design features not specifically called for in the Task Order, but on which developmental effort was considered to be desirable or necessary. To avoid tedious repetition, full details of all materials and components used in the construction of the flight assessment ATAGS are given only in Section 5.4.

(a) Don/Doff Ease Improvement.

Extensive development effort was applied to improve don/doff ease. Early in the program it was apparent that using separable zippers, extending from waistline to ankle along the garment restraint layer outer leg seams, was the most likely approach to effect the desired improvement. In developing this approach for adoption in the flight assessment ATAGS, attention has been paid to the need for coincident separation of the inner inflatable leg bladders at the outside-leg seams on opening of the outer restraint layer zippers. Attention also has been given to overlapping the fore and aft leg bladder separation lines. On zipper opening, to prevent full separation of the side seams of the upper section of the ATAGS restraint layer, the zipper sections between the waistline and (approximately) trochanter level are underlaid by a fabric gusset. This gusset, while retaining donning ease, permanently joins the fore and aft suit sections at these points. Other measures taken to reduce don/doff problems include providing conventional hook and bar clips at the suit upper side seams as well as short tape/webbing extensions to the zipper tabs and zipper tape ends to ease zipper operation. The result of the recorded development, aimed specifically at improving don/doff ease, is illustrated in Figure 4. During the course of development, consideration had to be given concurrently to the required compatibility of pressure-sock and flight boot wear with suit don/doff design features and procedures (covered separately in Section 5.1 (d)).

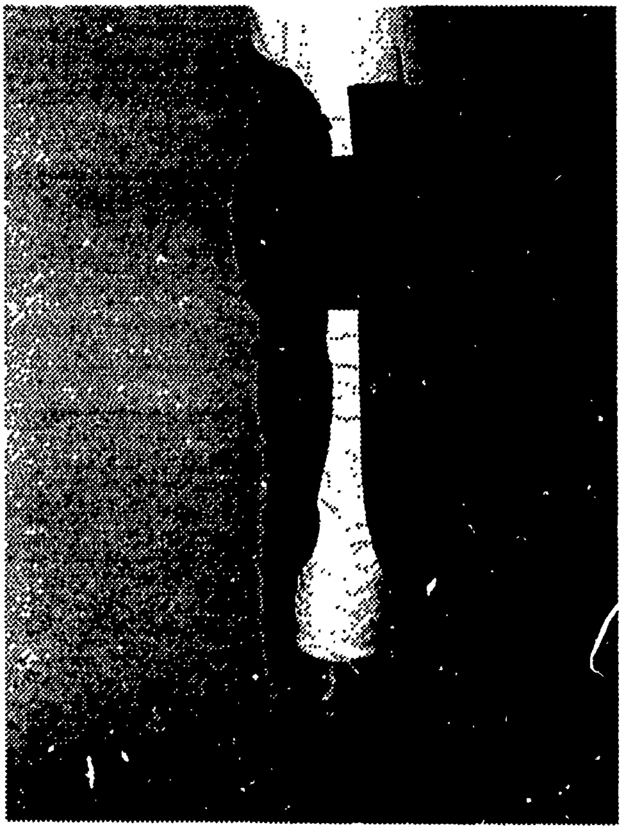

Figure 4. Zipper undone up to waist band showing bladder overlap edges, zipper run and upper gusset.

(b) In-flight Relief Facility.

To meet the stated requirement for in-flight relief in the ATAGS, a fly zipper has been incorporated in the conventional front-crotch area of the suit (Fig. 1). By joining the suit outer restraint layer and the local unpressurized crotch area of the suit inner bladder at the zipper tape edges, there is direct access to the suit interior via the opened zipper aperture. To locate the fly zipper at the suit front crotch area, it was necessary for the zipper upper end to intrude into the abdomen bladder area of the garment. Therefore, there is no abdomen bladder pressure coverage beneath the zipper upper end. A 7" fly zipper has been provided in all flight assessment ATAGS, irrespective of garment size, to minimize this loss of abdomen bladder coverage, particularly on smaller garments. To satisfy the in-flight relief requirement for all combinations of suit-subject fit, service assessment may indicate a need for longer fly zippers. If longer zippers are required, the implications of further zipper intrusion into the abdomen bladder area on pressure coverage and inflated abdomen bladder distortion will require reappraisal. Although the relief requirement has been provided in the ATAGS in the form dictated by the Task Order, KRUG Life Sciences has reservations in relation to in-flight accessibility, convenience and "in-use" comfort aspects of the zipper fly aperture approach. Further exploratory development of a permanently open (non-zipper) in-flight relief aperture is recommended.

(c) Suit Inflation Rate Improvement.

A number of measures have been taken to improve the G-onset suit inflation rate. Apart from the relevant pressurized suit volume-restraint measures (Section 5.1 (f)), emphasis has been placed on eliminating restrictions to suit pressurization airflow. The developed suit air entry system, illustrated in Figure 5, consists of a wire-wound, flexible, anti-kink/anti-crush air supply hose, permanently attached to the ATAGS. There is an appropriate make-break connector at the aircraft G system interface. At its air entry point, the suit is fitted with a flexible, molded rubber spout, appropriately angled for compatibility with the suit-to-aircraft supply hose run. To prevent distortion and the associated possibility of some occlusion of the ATAGS air entry spout, it is fitted with a metal sleeve insert. This insert provides a spigot, external to the rubber spout, for attachment of the air supply hose. The insert is secured in the air entry spout, and to the supply hose end, with appropriate clips.

To minimize the possibility of local occlusions pressurized airflow at vulnerable areas within the ATAGS inner bladder, spacer material has been developed and utilized. For this spacer material, illustrated in Figure 6, the achieved design objective was the production of an anti-occlusion material, which was free of the inherent stiffness and installed bulk of many conventional spacer materials. The developed approach consists essentially of parallel, raised ridges of an open-weave fabric, sewn to a coated fabric base which can be secured to the bladder inner wall with adhesive.

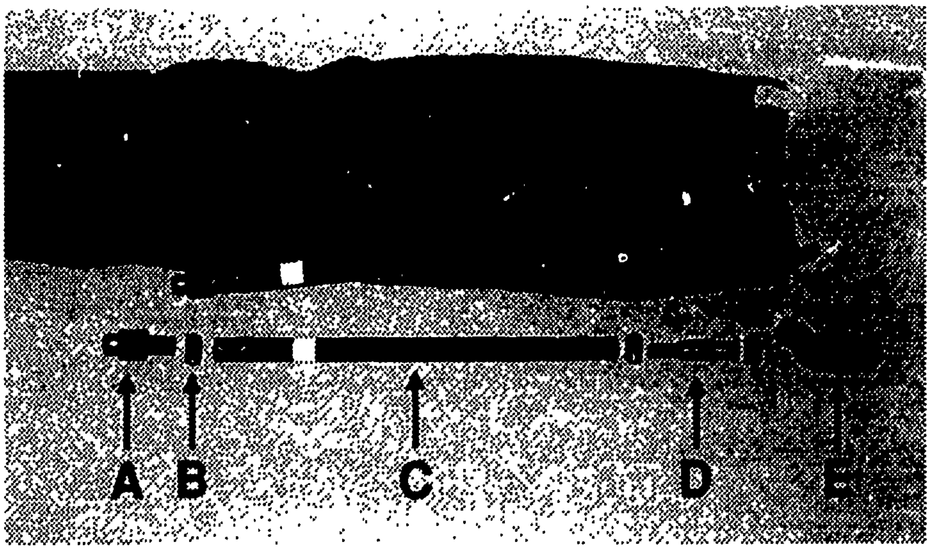

Figure 5. Air entry hose assembly with the individual assembly components.

A. Quick release connector.
B. Metal hose clamp.
C. Air entry hose.
D. Air entry spout sleeve insert.
E. Molded air entry spout.

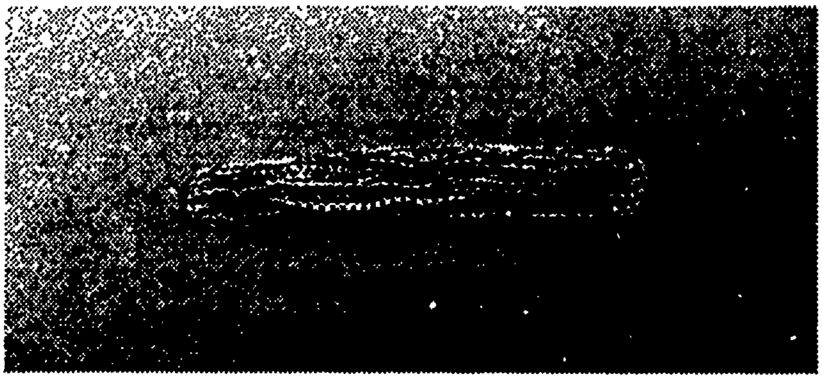

Figure 6. Spacer Material.

The precise location of the spacer fabric within the ATAGS bladder is shown on the relevant suit patterns referenced in Section 5.3. Because the fabricated spacer material was incompatible with RHF welding techniques, an alternative, reticulated foam spacer material was used in the construction of the bladder for ATAGS No. 09. In the development of the separable pressure sock, and its coupling to the ATAGS (Fig. 7), due consideration was given to the requirement for coincidental pressurization of both suit and socks. The improved inflation rate was quantified using the test procedure in Section 5.5.

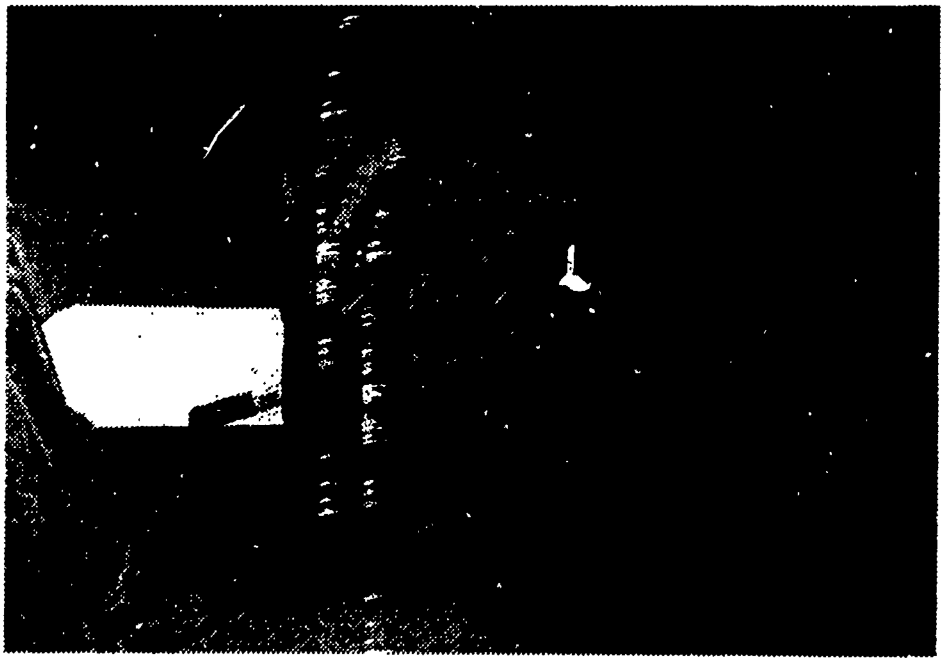

Figure 7. Pressure sock/ATAGS leg end.

(d) Ankle/Foot Comfort Improvement.

Full details of the program of work undertaken on the KRUG designed and developed pressure socks for use with the ATAGS are given in Appendix A. Since Appendix A was prepared in April 1990, two significant changes have been made to the recorded pressure sock details. These changes, which have been incorporated in the 6 flight appraisal ATAGS, submitted against Task Order No. 0001 requirements, are as follows:

In the laboratory evaluation of the ATAGS, there have been occasional complaints of local discomfort to the wearer's lower leg caused by the sock-suit connection assembly. To reduce or alleviate this problem, a pressure distribution pad has been introduced, located in a sock mounted "pocket" (Fig. 7). This pad effectively distributes point contact over a larger area from the suit-sock connection assembly to the wearer's lower leg.

In Appendix A, there is a reference to an ongoing appraisal of alternative, lighter-weight fabrics for sock construction to improve foot comfort. From this ongoing appraisal, a lighter weight coated fabric was identified, evaluated and introduced in the construction of the majority of pressure socks submitted for use with the flight appraisal ATAGS.

With the introduction of the ATAGS pressure sock as an additional item to the normal footwear assembly of aircrew, comfort considerations may dictate the need for an increase in the size of flight boot normally worn. Apart from the need for unobtrusive accommodation of the pressure-sock bulk within the flight boot, the standard of foot fit provided by the pressure socks is likely to be a major influencing factor in foot comfort. To satisfy sock sizing requirements, KRUG Life Sciences has defined an exploratory sock sizing tariff, to which pressure socks produced against Task Order No. 0001 conform. Details of this sock sizing tariff are given in Section 5.2.

The developed pressure socks submitted for use with the 6 minimal flight appraisal ATAGS incorporate all of the improved design features stipulated in the Task Order. The essential need for the pressure sock design concept to be compatible with the requirements of sock custom-fitting, at base level, additionally has been met.

Pressure sock manufacturing patterns are referenced in Sub-section 5.3; full details of all fabrics and components used in the ATAGS pressure sock development program are given in Section 5.4.

(e) Abdominal Bladder Shape Improvements.

Anthropometric differences between subjects, which have to be accommodated by any individual off-the-shelf suit size, impose restrictions on the extent to which custom-fitting of specific suit features is practicable. In relation to the Task Order requirement for fitting the shape of the ATAGS abdominal bladder top to the rib cage, a compromise has been pursued to satisfy multi-subject application requirements. In this compromise approach, the profile of the ATAGS abdominal bladder upper edge has been shaped, approximately, to conform with the lower rib-cage profile. However, the vertical location of the suit bladder upper edge, relative to the garment waist-line, has been selected to accommodate subject anthropometric differences without serious impingement of the pressurized suit abdomen bladder on the lower rib cage (Fig. 2, 3). In determining this vertical location, consideration has been given to the normal automatic lowering of the abdomen bladder top edge as the bladder pressurizes.

To improve pressurized garment comfort, the degree to which the abdomen bladder distends into the subject's abdomen is restricted, limiting the extent to which the inner and outer walls of the abdomen bladder can separate on pressurization. This improvement has been achieved by incorporating a coated fabric tie-web in the bladder, horizontally at its mid-line. The tie-web width, dictating the extent of bladder restraint, was arbitrarily chosen; contract time-scale constraints did not allow a desirable investigation of the acceptability of alternative tie-web widths. Limited centrifuge testing of the adopted tie-web configuration, however, did not elicit complaints.

Details of the ATAGS abdomen bladder shape, and the location of the tie-web are shown on innerbladder production drawings referenced in Section 5.3. Tie-web construction details are reproduced on only the one drawing indicated in Section 5.3.

(f) Pressurized Volume Constraint Improvements.

To satisfy the requirements for accommodating the anthropometric differences between subjects in specific off-the-shelf ATAGS sizes, and to minimize fitted suit pressurized volume, a system of girth adjustment lacing has been provided on the outer restraint layer of the ATAGS. This adjustment lacing (Fig. 8) provides for appropriate reductions in the ATAGS restraint layer circumferences at the waist-line, abdomen and buttocks and from the lower buttocks to the ankle on each leg. In selecting the precise suit locations for this lacing, consideration has been given to the need for meeting the requirements for comfort, for non-distortion of the abdomen bladder, and for maintenance of symmetry of the pressurized mobility design features, e.g., suit knee joints.

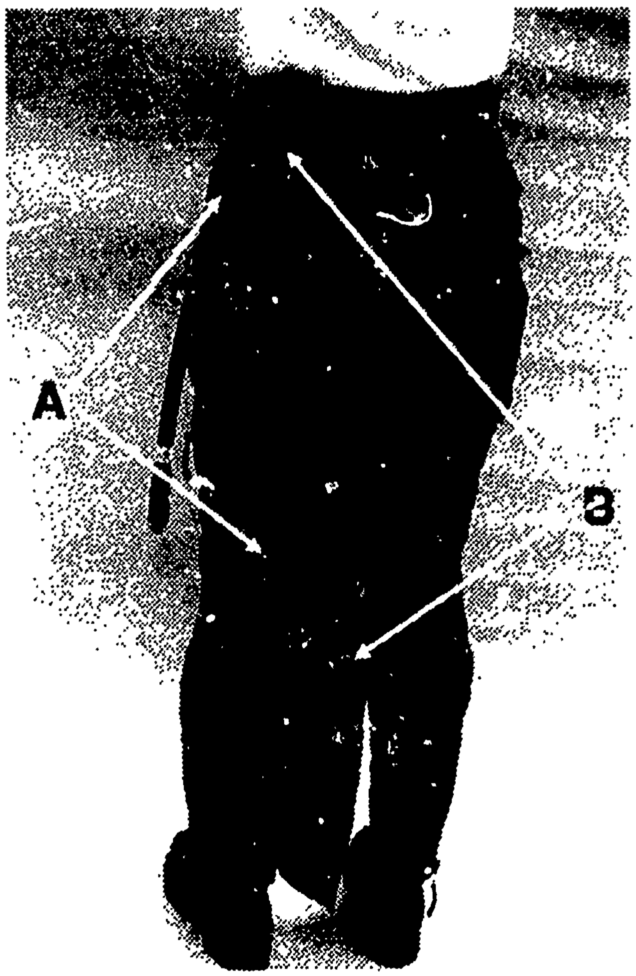

Figure 8. Adjustment lacing with cover flap.

A. Lacing
B. Cover flap

In its original form, it was assumed that the flight safety snagging hazard of exposed lacing would be nullified by wearing the ATAGS beneath a standard flight coverall. However, to comply with recent changes involving the use of the ATAGS as an external garment, screening covers have been introduced over the adjustment lacing to satisfy flight safety requirements. These covers (Fig. 8) span the unadjusted lacing width and are permanently secured by stitching to one side of the lacing to form a flap. The free end of the flap is secured by Velcro to the opposite side of the lacing, thus providing access to adjust the lacing. To reduce the possibly obtrusive bulk of the excess cover-fabric when spanning adjusted lacing, a simple system of adjustable cord has been introduced on the inside face of the lacing covers. Future consideration should be given to elasticizing the lacing cover width. Construction details for the adjustment lacing covers are available in pattern template form. Details of the location of the adjustment lacing are shown on the ATAGS production pattern drawings referenced in Section 5.3.

(g) Pressurized Mobility Feature Improvements.

Although in the ATAGS, counterpressurization is provided by inflatable bladders, the pressurized mobility problems are similar to those encountered in conventional full pressure suits. The ATAGS design, while needing to satisfy the unpressurized mobility requirements for wear outside and inside the aircraft, has to meet the requirements for aircraft G maneuver suit pressurization without significantly affecting comfort, mobility or seated posture. To satisfy these pressurized suit requirements, KRUG Life Sciences has concentrated on improving knee joint mobility and on minimizing the influence of suit pressurization on normal subject sitting posture.

In the adopted suit knee joint design, surplus fabric has been provided at the front knee to relieve the fabric of longitudinal stress and permit pressurized knee flexure. This surplus fabric, in discretely shaped segments, extends over the leg area sufficiently to accommodate the anthropometric range of USAF aircrew knee axis heights appropriate to any one size of ATAGS. Details of the knee design feature are illustrated in Figure 1; construction pattern drawings which show this feature are referenced in Section 5.3.

To reduce the adverse influences of suit pressurization on normal seated posture, adequate suit fabric has been provided longitudinally across the suit buttock panels. In the absence of bladder coverage over the ATAGS buttock area, the discrete fabric panels inserted in this area are applied only to the outer restraint layer of the ATAGS (Fig. 1). In satisfying the fit, mobility and sartorial requirements for the suit buttock area, contending design approaches were constructed and evaluated during the ATAGS development program.

The objective of development undertaken concurrently with suit buttock area design, was to induce seated-attitude creasing of the front groin-line at the intersection of the abdomen and upper front thigh bladder areas. After the make-up and assessment of 2 contending approaches, a finalized design, in which the bladder over a restricted area of the groin line of the suit was removed (Figs. 2 and 3), has been incorporated in the flight assessment ATAGS.

Details of the construction and configuration of the ATAGS restraint layer buttock area, and the location and configuration of the inner bladder groin-line mobility feature, are given on the appropriate suit construction pattern drawings referenced in Section 5.3.

5.2 ATAGS Sizing Programs.

Reference has been made to the manufacture and utilization of the first 6 ATAGS, (01 through 06), for the exploratory development of specified design features and for the establishment of garment sizing needs. In the initial suit sizing program, relevant criteria were identified in subjective fitting studies. Any indicated need for sizing changes to specific garment features was implemented progressively in the early developmental ATAGS.

The relevant anthropometric data for the experienced USAFSAM centrifuge rider nominated as test subject for this program, are given in Table 1. For comparison, some equivalent actual ATAGS measurements, typically required to provide an adequate garment fit on this subject, are also given in Table 1.

For sizing the flight assessment ATAGS, anthropometric data relevant to each of 20 nominated test subjects were provided by Edwards AFB (Table 2). Two subject measurements of particular importance in sizing and fitting the ATAGS are waist circumference and waist height (from floor). Figure 9 shows the distribution of the nominated Edwards AFB subjects superimposed on a waist circumference/waist height distribution plot of 2420 USAF aircrew; the distribution is based on data from the 1967 anthropometric survey of USAF flying personnel (2). Also superimposed on the Figure 9 plot, are tentative sizing grids indicating the discrete subpopulations of aircrew appropriate to each of 9 theoretical ATAGS sizes. From Figure 9, it is apparent that, based on their waist

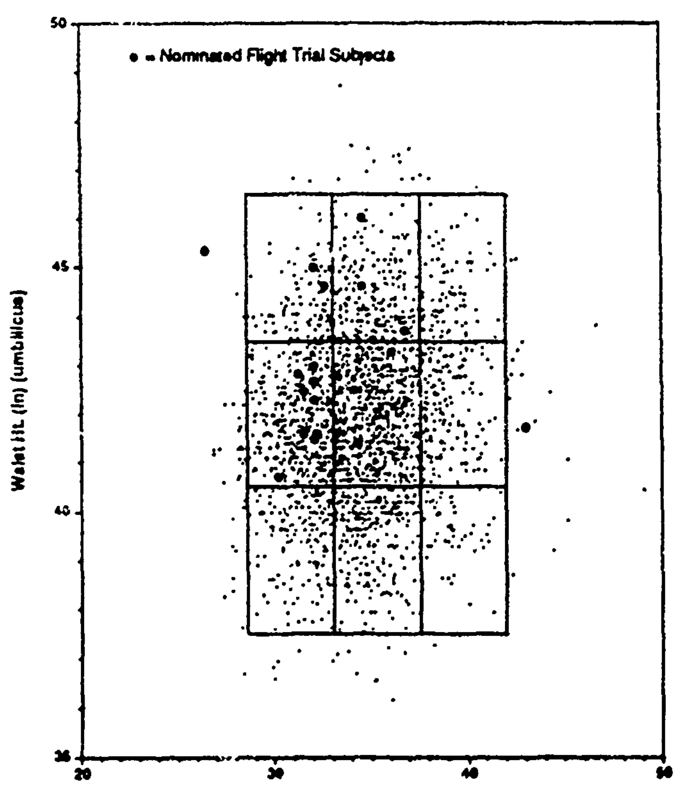

Figure 9. Location of nominated flight trial subjects on a waist circumference/waist height distribution plot of 2420 USAF aircrew (Survey Data Ref. 2).

TABLE 1. ANTHROPOMETRIC DATA FOR NOMINATED USAFSAM ATAGS TEST SUBJECT AND A SELECTION OF TYPICALLY REQUIRED ATAG SUIT MEASUREMENTS.

MEASUREMENT DEFINITION	SUBJECT MEASUREMENT	ATAGS MEASUREMENT
WEIGHT LB. (inches)	168.50	
STATURE (inches)	72.40	
WAIST CIRC (NATURAL INDENT) (inches)	33.20	36
WAIST CIRC (OMPHALION) (inches)	34.00	
WAIST HEIGHT (NATURAL INDENT) (inches)	46.15	
WAIST HEIGHT (OMPHALION) (inches)	43.66	
CROTCH HEIGHT (inches)	34.53	
PATELLA HEIGHT-TOP (inches)	21.65	
PATELLA HEIGHT-BOTTOM (inches)	18.19	
BUTTOCK CIRC (inches)	37.50	42
THIGH CIRC (inches)	22.30	25
KNEE CIRC (inches)	14.06	19
KNEE CIRC-FULLY BENT (inches)	18.50	
CALF CIRC (inches)	14.45	
ANKLE CIRC (inches)	8.80	
CROTCH LENGTH (OMPHALION) (inches)	-	
CROTCH LENGTH (NATURAL INDENT) (inches)	29.45	33
FOOT LENGTH (inches)	10.47	
FOOT BREADTH (inches)	3.66	
BALL OF FOOT CIRC (inches)	9.65	
HEEL/INSTEP CIRC (inches)	13.39	
INSTEP/SOLE CIRC (inches)	10.43	
*WAIST TO CROTCH LENGTH (inches)	11.62	11.75
*WAIST TO KNEE AXIS LENGTH (inches)	26.23	25.25

*NATURAL INDENT DATUM

TABLE 2. ANTHROPOMETRIC DATA OF NOMINATED FLIGHT TEST SUBJECTS[1].

SUBJECT REFERENCE	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	[illegible]
WEIGHT LB.	185.0	155.0	175.0	199.0	180.0	178.0	174.0	140.0	150.0	163.0	166.0	165.0	177.5	143.0	183.0	147.0	130.0	163.5	155.0	[illegible]
STATURE	71.58	69.10	69.50	72.05	70.87	75.08	70.16	70.10	67.05	72.40	71.06	[illegible]	70.08	68.27	69.29	63.96	72.91	68.70	71.65	[illegible]
WAIST CIRC. NAT. IND.	33.86	31.70	33.23	38.15	34.29	32.36	33.78	31.10	29.92	32.32	30.12	[illegible]	32.76	30.04	36.36	30.24	[illegible]	31.81	30.39	[illegible]
WAIST CIRC. UMB.	34.57	32.00	34.25	42.91	35.00	34.65	36.06	32.00	30.20	31.93	31.61	[illegible]	34.06	31.46	36.61	51.26	[illegible]	31.85	31.97	[illegible]
WAIST HT. NAT. IND.	46.89	44.00	43.80	44.92	44.65	47.12	46.42	44.90	41.81	46.14	44.92	[illegible]	44.29	42.48	45.83	44.02	47.09	42.01	44.65	[illegible]
WAIST HT. UMB.	44.76	42.30	41.34	41.70	43.46	46.06	43.35	42.70	40.79	45.06	42.48	41.61	42.60	41.65	43.62	42.87	46.20	41.50	43.07	[illegible]
CROTCH HT.	35.39	33.19	33.03	32.40	33.62	36.58	34.06	34.60	31.54	[illegible]	33.31	32.52	33.27	31.34	33.78	32.95	35.28	31.37	33.66	[illegible]
PATELLA HT. TOP	21.69	20.75	20.43	20.67	20.47	22.95	20.51	21.50	20.08	21.93	20.35	19.69	20.63	20.08	21.69	21.30	22.24	19.61	20.87	[illegible]
PATELLA HT. BOT.	19.25	18.30	17.72	18.07	17.60	20.67	18.03	19.20	17.64	19.33	18.23	17.72	18.43	17.28	18.35	18.62	19.53	17.72	18.82	[illegible]
BUTTOCKS CIRC.	39.25	36.46	40.12	41.58	40.55	39.37	40.10	36.06	35.87	38.03	38.31	[illegible]	38.19	37.40	39.53	36.77	33.94	38.31	37.95	[illegible]
THIGH CIRC.	22.40	20.12	22.72	23.74	24.69	23.07	24.88	19.30	21.34	21.30	21.73	[illegible]	23.50	21.34	20.09	21.77	18.35	23.15	20.47	[illegible]
KNEE CIRC.	14.29	13.43	15.04	15.83	16.97	15.04	15.67	13.70	13.98	15.55	14.76	[illegible]	[illegible]	13.98	15.08	13.86	13.66	15.12	14.06	[illegible]
KNEE CIRC. FULLY BENT	17.36	16.02	18.07	18.82	19.49	18.70	18.62	16.18	17.44	20.59	17.68	[illegible]	16.30	16.02	17.68	17.95	16.34	19.02	16.89	[illegible]
CALF CIRC.	14.72	13.54	14.33	16.61	15.67	14.88	15.20	12.80	14.49	14.84	14.88	[illegible]	15.28	13.70	14.96	13.62	12.64	14.45	14.37	[illegible]
ANKLE CIRC.	8.43	8.07	8.76	9.88	9.29	9.13	9.61	8.11	8.54	9.13	8.78	[illegible]	8.70	7.83	9.02	8.78	7.95	8.19	8.31	[illegible]
CROTCH LENGTH UMB.	25.34	25.75	28.15	28.62	29.02	28.46	27.13	24.53	26.85	28.54	27.20	[illegible]	26.46	26.14	30.59	25.94	25.98	27.24	26.34	[illegible]
CROTCH LENGTH WAT. IND	30.08	29.57	31.26	33.27	31.85	30.91	33.70	29.37	29.49	32.28	32.56	28.78	31.54	28.74	33.58	28.78	30.12	30.67	30.43	[illegible]
FOOT LENGTH	10.98	10.04	10.55	10.75	9.84	11.46	10.59	10.20	9.33	10.31	10.67	9.84	10.32	9.84	10.39	10.00	10.35	9.98	10.31	10.87
FOOT BREADTH	4.02	3.74	3.90	3.94	3.98	3.94	3.78	3.86	3.94	3.86	3.98	3.78	4.02	3.47	4.02	[illegible]	4.02	3.82	3.70	4.13
BALL OF FOOT CIRC.	9.76	9.25	9.80	10.35	9.65	9.53	9.69	9.29	9.45	9.88	10.08	9.25	9.72	8.27	9.65	9.53	9.84	9.29	9.13	10.12
HEEL/INSTEP CIRC.	12.17	12.24	12.32	13.58	12.87	13.07	12.68	12.00	13.11	13.19	12.91	12.20	12.32	11.58	13.47	13.19	12.05	11.97	[illegible]	12.87
INSTEP/SOLE CIRC.	9.72	9.21	9.69	10.47	9.61	9.92	9.53	8.94	9.25	10.08	9.92	9.45	9.61	9.06	10.08	9.29	9.84	9.33	9.45	10.51
*WAIST-CROTCH LENGTH	11.50	10.81	10.77	12.52	11.03	11.14	12.36	10.30	10.27	11.93	11.61	10.71	11.02	11.14	12.05	11.07	11.81	10.94	10.99	[illegible]
*WAIST-KNEE LENGTH	26.42	23.53	24.73	25.55	25.62	25.91	27.15	22.55	22.95	25.51	25.63	24.53	24.76	23.80	25.81	24.06	26.21	24.25	24.81	25.04

*AT NATURAL INDENT

[1] Except for weight all measurements are in inches.

circumference and waist height measurements, all except 2 of the nominated subjects fall within the theoretical sizing grids. More importantly however, from the point of view of sizing of the flight appraisal ATAGS, most of the remaining 18 subjects are grouped within adjacent sizing grids. The flight appraisal ATAGS have therefore been provided in 3 sizes to reflect this grouping. Their dimensional requirements have been determined from separate analyses of the anthropometric data for all test subjects falling within each of the 3 convenient subject groupings.

As with all off-the-shelf garment sizing systems, the selected ATAGS garment sizes represent a compromise; its ultimate acceptability can only be verified by extensive evaluation. With each of the ATAGS sizes, some accommodation of girth measurement differences between subjects is provided by the adjustable lacing. The common sizing boundaries between the 3 relevant sizing grids indicated at Figure 9 also allow a choice of suit size for subjects whose waist height or waist circumference falls on or close to the sizing grid boundaries.

In selecting measurements for each of the 3 defined garment sizes, guidance was provided on suit-subject sizing relationship from the findings of the early exploratory studies. In this choice of measurements, consideration had to be given to satisfying garment fit standards for all subjects appropriate to each garment size.

The planned flight trials of the ATAGS should provide feedback on the degree of accommodation provided by the 3 ATAGS sizes. Such information will be required to support the definition of formal garment sizing to accommodate the USAF aircrew population as a whole.

With a view to the future for formal sizing of the ATAGS, an assumption has been made that sizing will be based on waist circumference (omphalion) and waist height (omphalion) controls (Fig. 9). These 2 measurements not only directly reflect the most important body circumferential and length measurements requiring a high standard of garment fit, but also correlate reasonably well with respective subsidiary circumferential and length measurements. The inter-size incremental steps are 75 mm (approximately 3 in.) for waist height and 113 mm (approximately 4.5 in.) for waist circumference, upon which the sizing grids at Figure 9 are based; these incremental steps have been assumed to be the maximum ranges of these body dimensions which can be accommodated in a single garment, without unacceptable degradation of fit. To some extent the validity of this assumption depends upon the efficacy of the ATAGS girth adjustment. Based on USAF aircrew anthropometric data (2), the sizing grids indicated at Figure 9 encompass 96% of the aircrew population. Analysis of data on some of the relevant subsidiary measurements (e.g., crotch length and buttock circumference) does, however, indicate that it would not be practical to cater for some of the extreme ranges of these measurements in the suits.

An example of computed anthropometric data for all subjects comprising a typical Figure 9 size-grid population is given at Table 3. This table presents subpopulation percentile data from which the suit sizing measurements would be defined.

In the absence of definitive guidance on ATAGS pressure sock sizing requirements, an assumption has been made that, for the USAF aircrew population as a whole, a minimum of 8 sizes will be required. These 8 sizes span 8.5 - 12.0 in. subject foot lengths, in half inch increments. All

TABLE 3. ANTHROPOMETRIC DATA.
GROUP 5 N=768

VARNAME	MIN	P1	P2	P3	P5	P50	P95	P97	P98	P99	MAX
WAIST CIRC.	32.99	32.99	33.11	33.15	33.19	35.00	37.13	37.24	37.32	37.40	37.44
WAIST HT.	40.47	40.47	40.47	40.59	40.63	41.97	43.27	43.35	43.35	43.39	43.43
WEIGHT (lb)	146.00	151.00	152.00	155.00	157.00	178.00	198.00	200.00	203.00	208.00	219.00
STATURE	65.47	67.13	67.36	67.52	67.76	69.90	72.13	72.48	72.83	73.35	73.78
BUTTOCK CIRC.	34.72	36.06	36.46	36.69	37.05	39.21	41.57	41.89	42.05	42.68	43.31
UPPER THIGH CIRC.	20.00	20.67	20.83	21.18	21.57	23.46	25.67	25.91	26.30	26.65	27.64
KNEE CIRC. BENT	13.94	14.33	14.41	14.53	14.65	15.55	16.73	16.85	17.01	17.13	17.72
KNEE C. STANDING	13.86	14.06	14.25	14.29	14.41	15.35	16.46	16.61	16.69	16.85	17.44
TROCHANTERION HT.	34.49	34.92	35.24	35.31	35.51	37.01	38.54	38.70	38.74	38.86	39.72
ILIOCRISTALE HT.	40.28	41.06	41.26	41.42	41.54	43.07	44.57	44.76	44.88	45.16	45.47
BUTTOCK HT.	33.07	33.43	33.62	33.82	34.02	35.45	37.01	37.20	37.36	37.72	38.31
CROTCH HT.	30.91	31.42	31.65	31.85	32.01	33.46	35.04	35.16	35.35	35.63	36.18
PATELLA-TOP HT.	19.06	19.41	19.57	19.61	19.76	20.75	21.69	21.85	21.97	22.17	22.52
CALF HT.	12.36	12.64	12.83	12.91	13.11	14.02	15.08	15.20	15.28	15.47	15.75
KNEE HT. SITTING	20.20	20.79	20.94	21.02	21.10	22.05	22.91	22.99	23.19	23.31	23.62
BUTTOCK-KNEE LENGTH	21.73	22.44	22.52	22.64	22.76	23.94	24.96	25.12	25.20	25.35	25.91
CROTCH LENGTH	23.35	24.84	25.35	25.51	25.87	27.99	30.31	30.75	30.94	31.38	33.11
CHEST CIRC.	34.76	35.35	35.91	36.14	36.38	39.21	42.24	42.83	43.23	43.58	45.98
CALF CIRC. - LEFT	12.52	13.07	13.27	13.39	13.50	14.65	15.79	15.94	16.14	16.38	17.72
FOOT LENGTH	9.45	9.84	9.92	10.04	10.08	10.67	11.30	11.42	11.46	11.50	11.81
INSTEP LENGTH	6.85	7.09	7.17	7.20	7.28	7.87	8.35	8.43	8.46	8.54	8.86
BALL OF FOOT BREADTH	3.39	3.46	3.50	3.54	3.58	3.86	4.13	4.21	4.21	4.25	4.49
LATRL. MALLEOLUS HT.	2.20	2.32	2.36	2.40	2.44	2.76	3.07	3.15	3.19	3.27	3.39
ANKLE CIRC.	7.60	7.91	8.03	8.07	8.15	8.86	9.57	9.69	9.80	9.92	10.47
HEEL-ANKLE CIRC.	12.32	12.44	12.56	12.60	12.68	13.39	14.17	14.25	14.37	14.45	14.96
INSTEP CIRC.	9.06	9.25	9.37	9.45	9.53	10.12	10.83	10.98	11.06	11.22	11.57
BALL OF FOOT CIRC.	8.54	8.70	8.86	8.94	9.09	9.84	10.59	10.71	10.79	10.91	11.10
GLUTEAL FURROW HT.	29.57	30.04	30.28	30.35	30.55	31.93	33.35	33.43	33.54	33.86	34.41
FIBULA HT.	1.65	1.73	16.10	16.30	16.42	17.28	18.19	18.31	18.43	18.54	18.94
WAIST (omph) HT. - CROTCH HT.	6.14	6.85	6.97	7.09	7.24	8.50	9.61	9.80	10.00	10.16	10.51
WAIST (omph) HT. - PATELLA (top) HT.	19.49	19.76	20.00	20.16	20.28	21.22	22.20	22.36	22.44	22.64	23.11
WAIST (omph) BUTTOCK HT.	3.98	5.08	5.16	5.24	5.35	6.46	7.56	7.76	7.87	8.23	8.74
KNEE CIRC. HT.	17.95	18.27	18.43	18.50	18.62	19.57	20.51	20.59	20.67	20.87	21.34
KNEE CIRC. HT. - FIBULA HT.	0.98	1.34	1.50	1.54	1.65	2.28	2.83	2.95	2.99	3.11	3.31
PATELLA (top) HT. - FIBULA HT.	1.93	2.40	2.52	2.60	2.72	3.46	4.09	4.13	4.21	4.29	4.72
PATELLA (top) HT. - KNEE CIRC. HT.	0.51	0.75	0.79	0.83	0.87	1.14	1.50	1.54	1.57	1.61	1.77

Weight is reported in pounds. All other measures are reported in inches.

ATAGS socks, irrespective of size, have been provided in one height, or cuff length, to meet the requirement for guaranteed continuity of pressure bladder coverage at the sock-suit interface. For ATAGS Task Order purposes, formal sock patterns, and pressure socks have been produced in only the 5 sizes relevant to the foot sizes of the nominated flight trials team members at Edwards AFB.

5.3 Pattern and Template Production.

Formal patterns have been produced and retained to record all stages of the ATAG suit development. In the early stages, during the exploratory transition from the U.P.S. to ATAGS design format, these patterns were produced directly as templates, in pattern card, to facilitate the rapid production of assessment garments.

For ATAGS 05 through 12, formal numbered drawings were produced, suitable for dye-line reproduction. From dye-line copies, pattern card templates were constructed for all of the fabric component parts of each size. These templates were used for fabric marking prior to pattern cutting.

In the initial absence of computer-aided drafting facilities, it was expedient to produce all pattern drawings manually. This technology is now available to KRUG Life Sciences and has been utilized for the reproduction of manually drafted patterns, pending a requirement for new sizes of suit patterns.

An example of a typical set of ATAGS production patterns at reduced scale is given in Appendix B. A pattern drawings schedule for the sizes covered by ATAGS 05 through 12 and for the produced sizes of ATAGS pressure socks is given in Appendix C.

5.4 ATAGS Materials and Components.

In selecting materials and components for ATAGS production, primary consideration has been given to their suitability for the intended purpose and their compatibility with ATAGS flight task requirements. Where possible and practical, we have selected materials and components which meet the requirements of recognized specifications. When it has not been possible to meet specific ons, every effort has been made, in appropriate laboratory proving, to establish and confirm mat als suitability.

Contract time constraints limited the search, acquisition, and evaluation process for altern...tive and potentially more acceptable fabrics. In the case of the ATAGS outer restraint layer, a proven, plain weave, 4.3 oz. Aramid (Nomex) material has been used throughout. Investigation does, however, suggest the future availability of fabrics based on Kevlar which, having reduced stretch may be more appropriate to the ATAGS requirements. One such development by Arville Textile Ltd., U.K., incorporates threads comprising a Kevlar core with a Viscose sheath.

For the inner bladder of the ATAGS, a polyurethane coated 6.0 oz. nylon cloth has been adopted. This Military Specification-compatible fabric satisfies the requirements for the application of gluing or R.H.F. welding construction techniques. For comfort, a softer, more flexible fabric is more desirable for the ATAGS inner bladder. At a late development stage, a lighter weight (4.87 oz) polyurethane proofed fabric was identified, and acquired. Although too late for suit bladder application evaluation, this lighter weight fabric has been introduced for the ATAGS pressure socks. An ATAGS Materials and components schedule is listed in Appendix D. Details given in this Appendix include: Item description, purpose, quantity, relevant specifications and manufacturer/ supplier.

5.5 ATAGS Testing Program.

The test stand arrangement for pressure testing the ATAGS consisted of a solenoid valve, a flow meter, a pressure transducer, a Macintosh computer, LabView Software, an electronic interfacing circuit, and other miscellaneous connections. The flow meter and pressure transducer produced output signals of 0-5 Vdc for the range of 0-50 scfm and 0-15 psig respectively. Monitored parameters were the pressure decay rate of an inflated ATAGS and flow rate. The pressure decay over time was indicative of the leakage rate whereas the flow meter was used to record the maximum flow achievable from the set conditions of regulated pressure and plumbing.

Static pressure testing was conducted on isolated areas of the ATAGS ensemble (i.e., the socks being separate entities). This method of testing provided for better evaluation of suit component integrity. The testing pressure was 13.25 psig, which was more than twenty-five percent greater than that which the ATAGS would be subjected to in service (i.e., 10.5 psig would be the maximum). The suits attaining the test pressure were ruled as being worthy for centrifuge testing and flight evaluation. Suits 5, 6, 8, 9, 10, 11, and 12 have met the criteria. Figure 10 shows an ATAGS being tested for structural integrity.

In addition to the static test criteria, suit leakage was acceptable providing (1) the leakage rate was below that which the anti-G valve was capable of delivering and (2) the pressure decay rate of suits repetitively inflated had not substantially increased. The available flow through an anti-G valve was published in USAFSAM-TR-86-36-PT-4. That report revealed flow characteristics of the ALAR high-flow anti-G valve which is the one in use in the human-use centrifuge and in the F-15 and F-16 fighter aircraft. At a $+G_z$ level of 2, flow through the valve was approximately 1.75 scfm at an upstream pressure of 150 psig. The open flow value measured on the ATAGS test stand with a regulated pressure of 15 psig was 1.39 scfm; hence, suits achieving the static qualifying pressure have leakage rates below 1.39 which verifies that the ALAR High-flow anti-G valve can provide the flow necessary to maintain suit pressure. Suits 5, 6, 9, 10, 11, and 12 were inflated to 13.25 psig thirty times and allowed to deflate. The pressure decay of the first cycle compared to the last cycle was within 50% for each of the suits. Suit 8 had a 51% increase of pressure decay with respect to time from first to last pressure deflation of the cycles; yet, Suit 8 took the longest time to deflate. Therefore, seven suits are worthy of flight evaluation including Suit 8. An example of data obtained from a pressurized test is in Appendix E.

Figure 10. Inflated ATAGS on a manikin during static testing.

To verify that ATAGS was pressurizing uniformly and that flow impedance was minimal, pressure taps were installed in the abdominal, thigh, and calf areas of one ATAGS for a centrifuge run using a centrifuge panel subject. The pressures monitored, with respect to $+G_z$, in the suit were similar and closely followed the pressure profile of the monitored ALAR high-flow anti-G valve. Subjects who wore the ATAGS have commented on the suit's quick and even pressurization.

6. REFERENCES.

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2. AGARDOGRAPH No. 205. A Review of Anthropometric Data of German Air Force and United States Air Force Flying Personnel 1967-1968.

APPENDIXES

A. The Design and Development of Pressure Socks for Use with the Advanced Technology Anti-G Suit (ATAGS) (Report No. RFP. F33615-89-C-0603).

B. A Typical Set of ATAGS Production Patterns (To Reduced Scale).

C. ATAGS Pattern Drawings Schedule.

D. Advanced Technology Anti-G Suit (ATAGS) - Material and Components Schedule, ISSUE 1.

E. Typical Pressure Test Results

F. Edwards AFB Flight Test Protocol - ATAGS Evaluation

G. ATAGS LabView Logic Diagram

APPENDIX A

THE DESIGN AND DEVELOPMENT OF PRESSURE SOCKS FOR USE WITH THE ADVANCED TECHNOLOGY ANTI-G SUIT (ATAGS)

(REPORT NO. RFP. F33615-89-C-0603)

1. INTRODUCTION

Early design proposals for an extended cover anti-G suit submitted by KRUG Life Sciences to USAFSAM (October 1986) included a requirement for full pressurization of the ankles and feet. In garments produced in response to these proposals, a compromise solution was adopted in which partial foot pressure coverage was provided by inflatable, wrap-around pads, extending from the suit leg-end bladders (Fig. 1). With this configuration of "sock", the early prototype ATAGS, (then designated the Uniform Pressure Anti-G Suit), was flight tested at Edwards AFB in September/ November 1988 (Ref. 1).

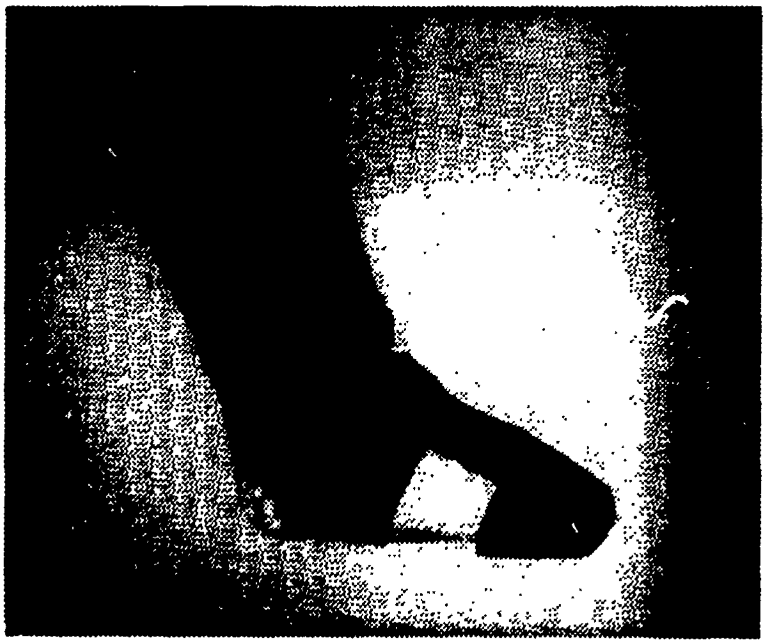


Fig. 1 - Partial foot pressure coverage.

In August 1989, under USAF Contract No. F33615-89-C-0603, KRUG Life Sciences was tasked with the further development of the Advanced Technology Anti-G Suit (ATAGS) and the production of 12 garments for Service flight evaluation. In this more recent development program, a requirement for the garment to include the provision of complete pressure coverage of the lower limbs, ankles, and feet has been assumed. In this program, a number of factors have influenced design decisions relating to the satisfying of the ankle and foot pressurization requirement. This report records those influencing factors and describes the progressive development and details of the current development status pressure sock.

2. ATAGS PRESSURE SOCK - EARLY DEVELOPMENT

In the early stages of the current ATAGS development program, expediency, to satisfy an urgent need for early suit evaluation, dictated the adoption of integrated pressure socks. These socks had to meet the sizing requirements of nominated test subject(s) and were permanently attached to, and an integral part of the leg ends of the prototype ATAGS.

In the ATAGS design, donning/doffing zippers extend from the waistline to ankle, down the outside leg seams. To ensure continuity of pressure coverage behind the zippers, the front leg bladder sections of the garment are designed to overlap the zipper and the back-leg bladder section edge (Fig. 2). With the developmental integrated pressure sock, this bladder overlap was utilized to provide a continuing bladder overlap gusset in the sock, extending from the suit/sock interface to the ankle (Fig. 3). By this means, bladder gusset opening facilitated the donning passage of the wearer's heel/instep circumference into the sock without the need for an excess of sock girth in that area.

Fig. 2 - Leg bladder overlap scheme.

Fig. 3 - Inseparable sock.

These integrated pressure socks were fabricated in 5.5/6.5 oz polyurethane coated nylon fabric, utilizing glued and taped seam construction. The upper peripheries of the inner and outer sock layers were bonded, respectively, to the inner and outer leg bladder ends, thus providing a direct pressurizing gas passage from the suit to the socks.

3. FACTORS INFLUENCING ATAGS PRESSURE SOCK DESIGN

Consideration of the logistic and cost implications of satisfying the need for individually sized pressure socks, when the ATAGS is issued to aircrew, indicates the impracticability of providing production ATAGS with integrated, or permanently attached socks. There is, therefore, a requirement for the pressure socks to be separable from the ATAG garment, to satisfy sock size selection requirements at Base level. The separable sock approach also meets the need for a sock replacement facility for hygiene purposes, or, in the event of wear-tear damage to that more vulnerable component of the ATAGS assembly.

To meet the aircrew population needs there is a requirement for the pressure sock to be provided in a range of sizes. Each size of sock must be compatible for wear with an appropriate range of ATAGS sizes.

In the design of the basic ATAGS, the lower limb pressure bladders terminate at or above the flight boot cuff-top level. To ensure continuity of pressure coverage of the subject at the suit-sock interface, the pressure sock length must be sufficient to provide an overlap of the sock and lower limb pressure bladders. This overlap must be guaranteed for all subject leg lengths appropriate to each of the basic ATAGS sizes.

The pressure sock design must cater for the donning passage of the subject's heel-instep circumference in a manner which does not leave excessive sock fabric in this area which has to be accommodated in the flight boot instep.

With a separable sock, means must be provided for transferring pressurizing air, at an appropriate rate, from the ATAGS lower limb bladders to the pressure socks. Any couplings incorporated to effect this transfer must be located above flight boot cuff-top level and be accommodated in a manner which avoids wearer discomfort.

The requirement for rapid and coincident pressurization of the ATAGS lower body and sock bladders, with 'g' onset, dictates the avoidance of restrictions to the passage of pressurizing air between the sock air inlet and the sock sole. To meet this requirement in the restricted sock bladder interspace, between the foot and flight boot, unobtrusive and discretely located inter-bladder spacer material/fabric is required in the sock.

To satisfy an over-riding requirement for wearer comfort, consistent with meeting essential gas-holding, strength and wear-tear requirements, the impervious fabric from which the pressure sock is constructed must be of minimum thickness and be soft and pliable. The avoidance of discomfort must equally be a consideration in the choice of pressure sock construction methods.

4. ATAGS SEPARABLE PRESSURE SOCK CURRENT DEVELOPMENT STATUS

Since December 1989, ATAGS pressure sock developmental effort has been concentrated upon the satisfying of the requirements specified in Section 3. A design of separable sock has been established and prototype socks have been produced in a number of sizes for Service evaluation.

In this prototype separable pressure sock (Fig. 4), the outside leg seam, bladder overlap gusset feature of the earlier integrated sock has been retained. This, while providing continuity of ankle/lower leg pressure coverage, also accommodates heel/instep girth donning without residual excess sock girth at the instep.

Fig. 4 Separable sock.

A common sock length for all sock sizes has been established which provides the necessary overlap between the sock and suit lower leg bladders for all suit/subject sizes.

The current development status pressure sock is designed for attachment to the ATAG garment at Base Survival Equipment Section level (Fig. 5). Once made, this attachment remains intact until a change of pressure sock is dictated. This approach has minimized the dimensions and bulk of the connectors which have to be accommodated between the ATAGS lower leg and sock bladders. Garment donning studies have shown that, with the socks permanently linked to the ATAGS in this manner, the socks, flight boots and suit can be donned sequentially without significant problems. While this linked-sock approach has many attractive features, a possible Service requirement for a quick-disconnect coupling at the sock-suit interface has been considered. However, within the time-scale of the current ATAGS 12 month development contract, it has not been possible to find, or develop a suitable in-line, quick release connector which satisfies the air-flow, low bulk and mated-integrity requirements.

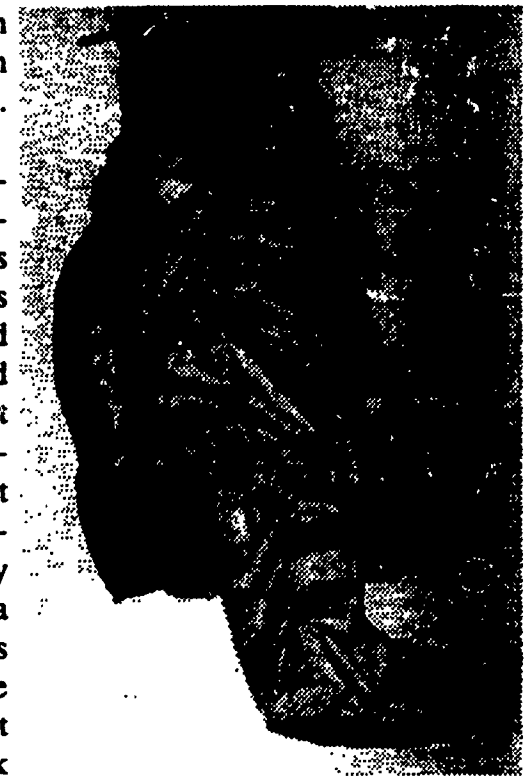


Fig. 5 - Attachment of sock with the ATAGS

To facilitate the transfer of suit pressurizing air from the ATAGS lower limb bladders to the pressure socks, 90° angled rubber spouts are located in the inner wall of the lower leg bladders and the outer wall of the sock bladders. These spouts are aligned vertically (Fig. 5) and positioned such that, in accommodating the required range of subject leg lengths, they can either be directly coupled with an adapter or separated vertically by a short (up to 3 inch) length of intermediate tubing. These locations of the couplings provide for donning of the unzipped ATAGS, donning of the pressure socks, followed by donning of the flight boots if required at this stage, and finally, closing of the ATAGS side seam zippers.

Development of the ATAGS has included the design and fabrication of strip spacer material (Fig. 6) which is located at strategic positions in the pressure bladders to prevent occlusion of the necessary air passages. This spacer material, which was specifically developed to provide a soft, supple, minimum bulk anti-occlusion medium, is incorporated in the pressure sock bladder at the outside leg seam position.

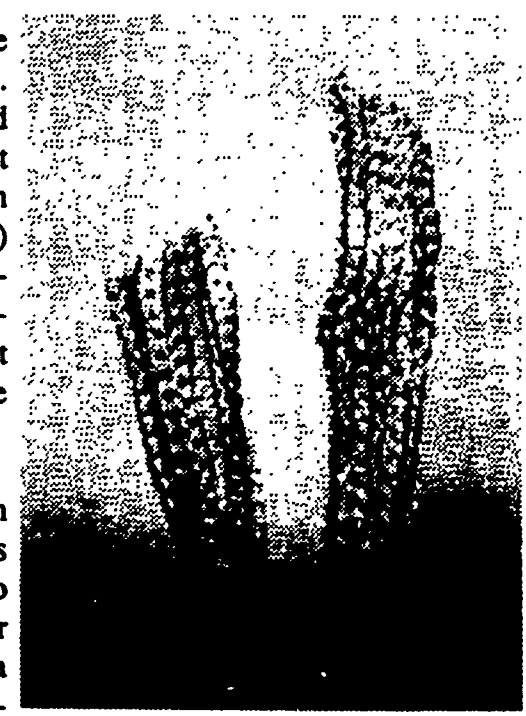


Fig. 6 - Spacer material.

The current status developmental pressure sock is fabricated from 5.5/6.5 oz polyurethane proofed nylon fabric, utilizing glued and taped construction. This material is amenable to construction by welding techniques if required at a later development stage. While no serious criticisms have been leveled at the current choice of sock material from limited wearer and centrifuge tests of the ATAGS assembly, an ongoing appraisal of alternative, lighter-weight fabrics for sock construction is being pursued.

To ensure retention of the sock bladder overlap gusset, subsequent to garment donning, Velcro tabs are provided on the socks.

5. COMMENTS AND OBSERVATIONS

Limited laboratory and centrifuge subject experience of wearing the separable pressure sock, in conjunction with the ATAGS, have not elicited any major criticisms of the sock design. The current design status sock will be evaluated by Service aircrew during planned flight trials of the ATAGS assembly, at Edwards AFB, in early1991.

6. REFERENCES

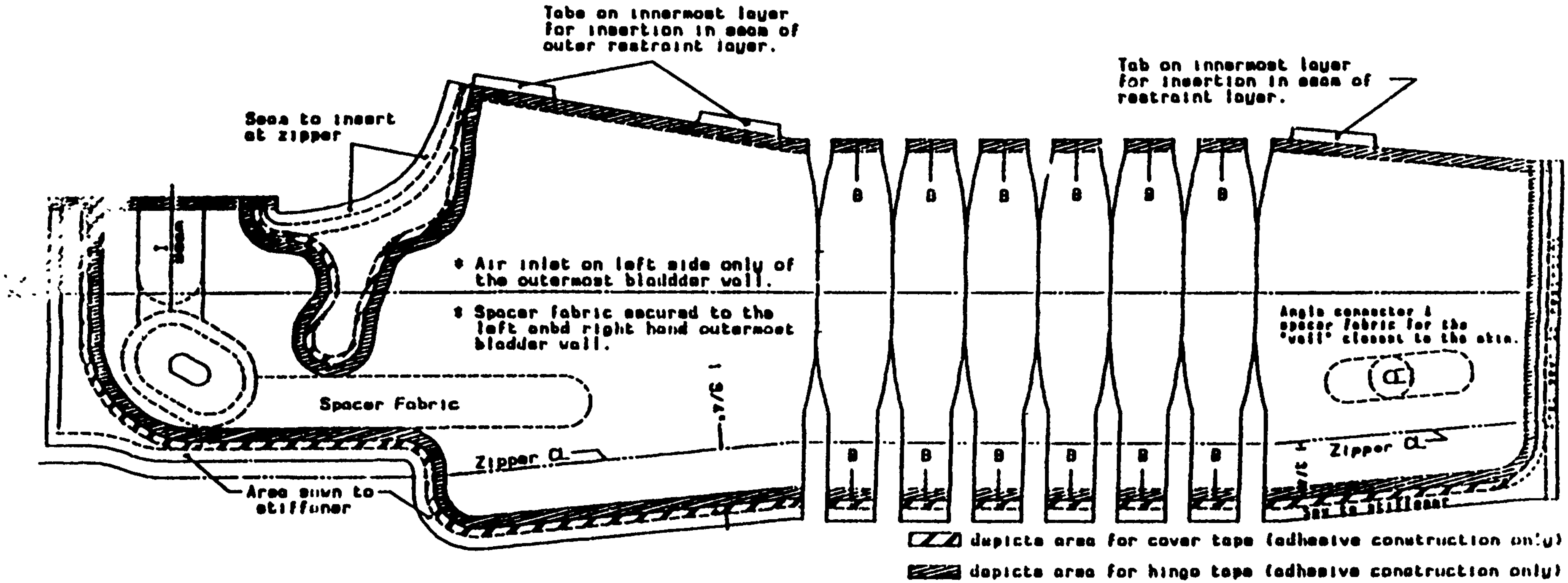
Helms, S.J., W.P. Daily, G.A. Bass, and O. Gorgensen. USAFTPS-TR-88A-4, Limited qualitative evaluation of the advanced technology anti-G suit (ATAGS).

7. ACKNOWLEDGMENTS

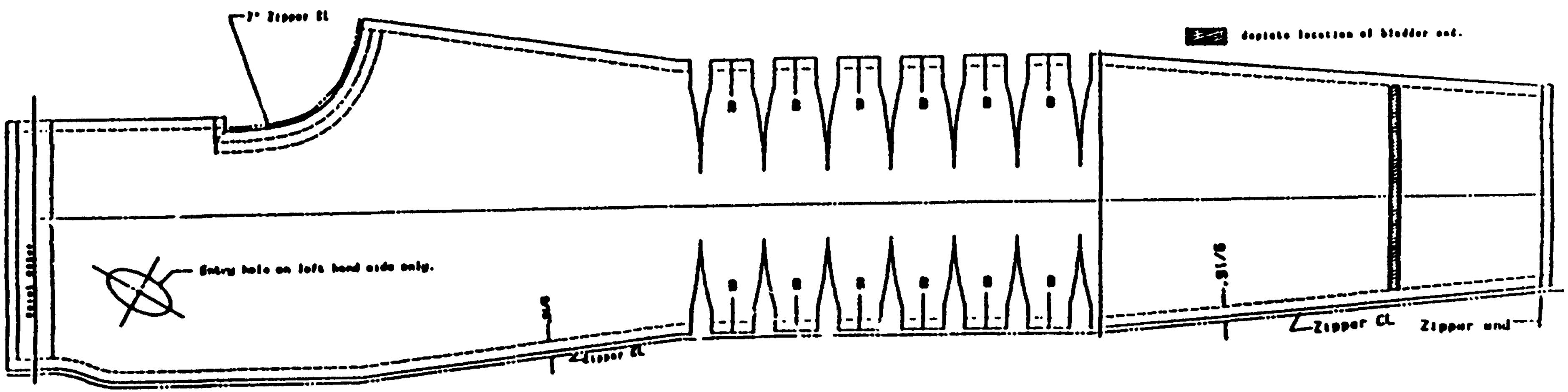
The authors acknowledge the dedication and expertise of the KRUG International Staff in the Life Support Equipment Development Laboratory, USAFSAM, Brooks AFB, in the production of the prototype garments. Thanks must also go to Capt Beneditz (USAFSAM) and Sgt Baker (USAFSAM) for their uncomplaining support as centrifuge riders and to Mrs. Dorothy Baskin for her assistance in the preparation of this Report.

APPENDIX B

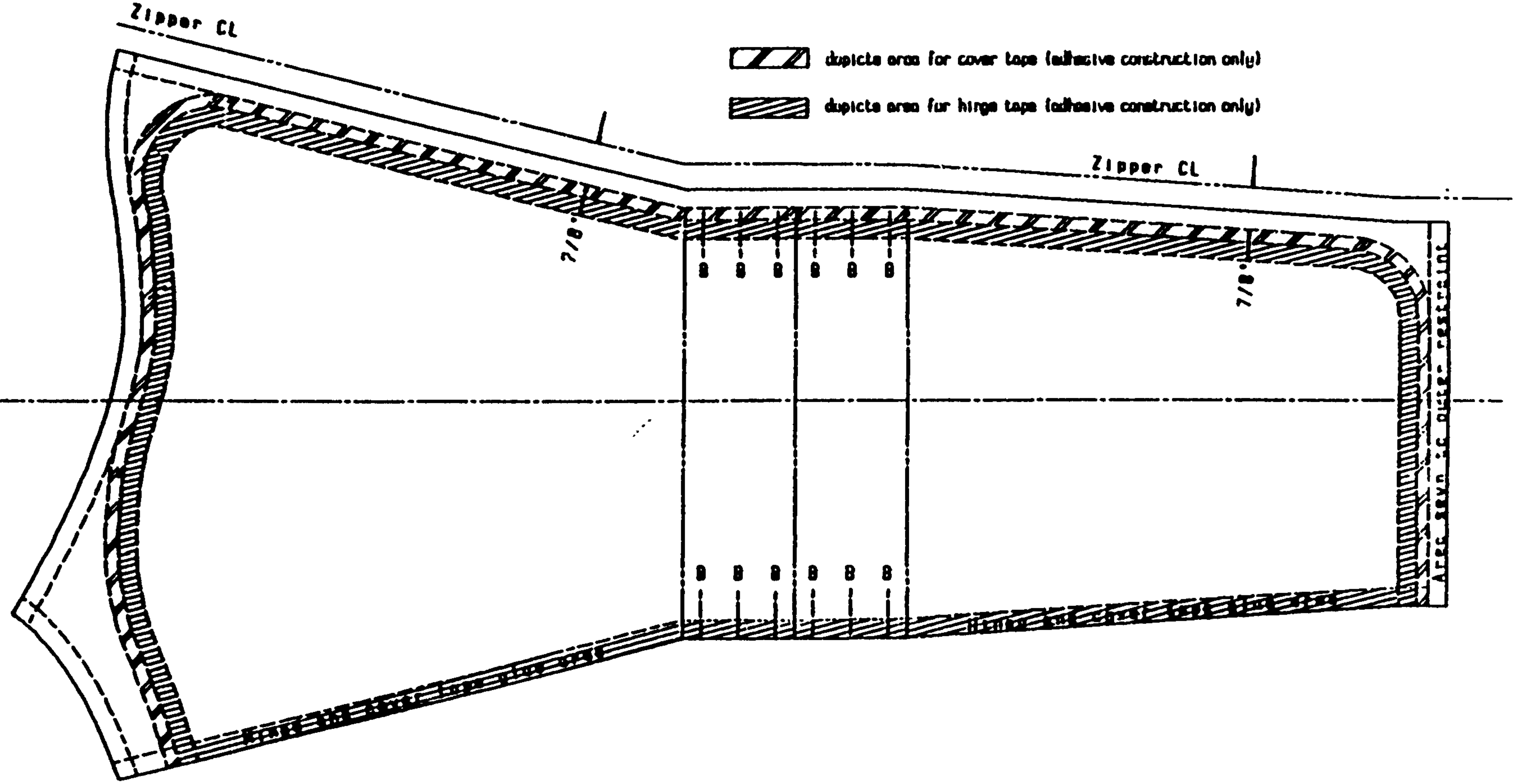
A TYPICAL SET OF ATAGS PRODUCTION PATTERNS
(TO REDUCED SCALE)



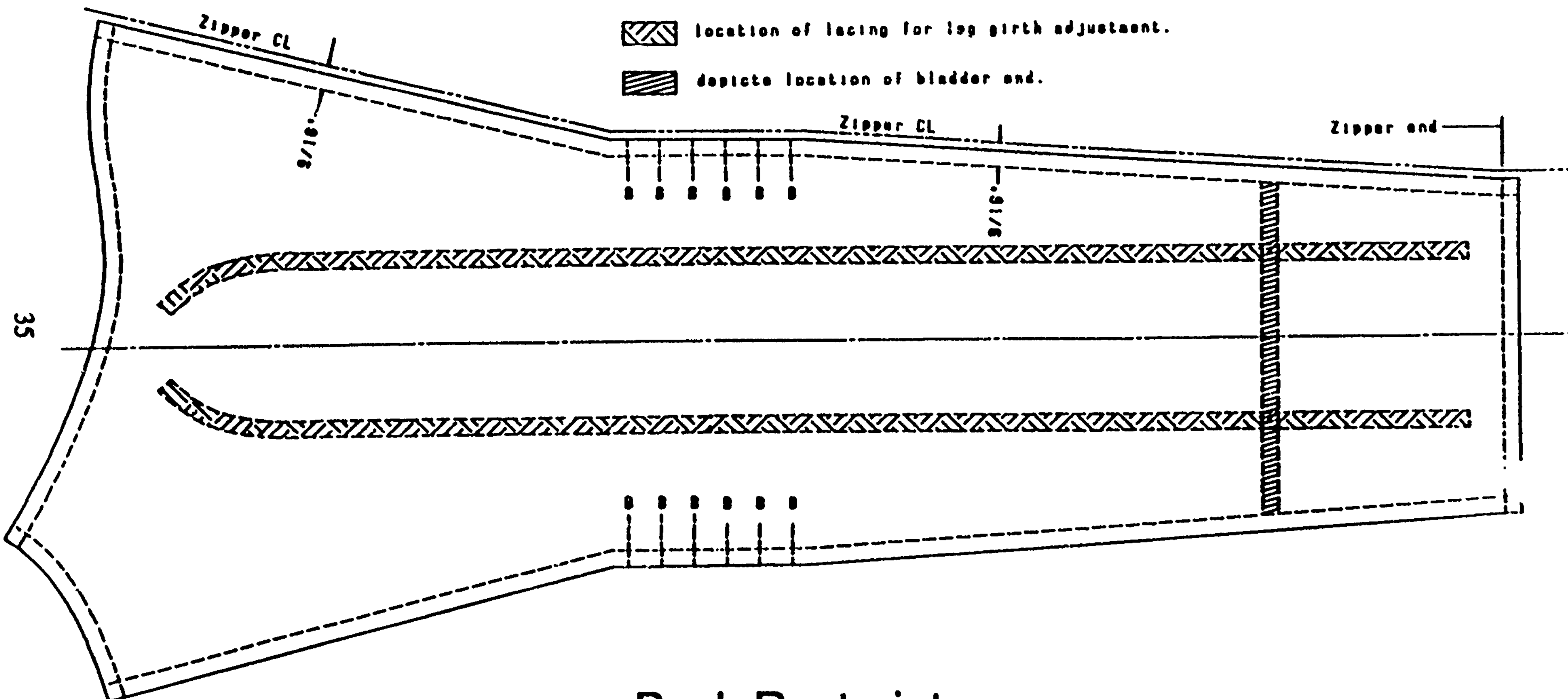
Front Bladder



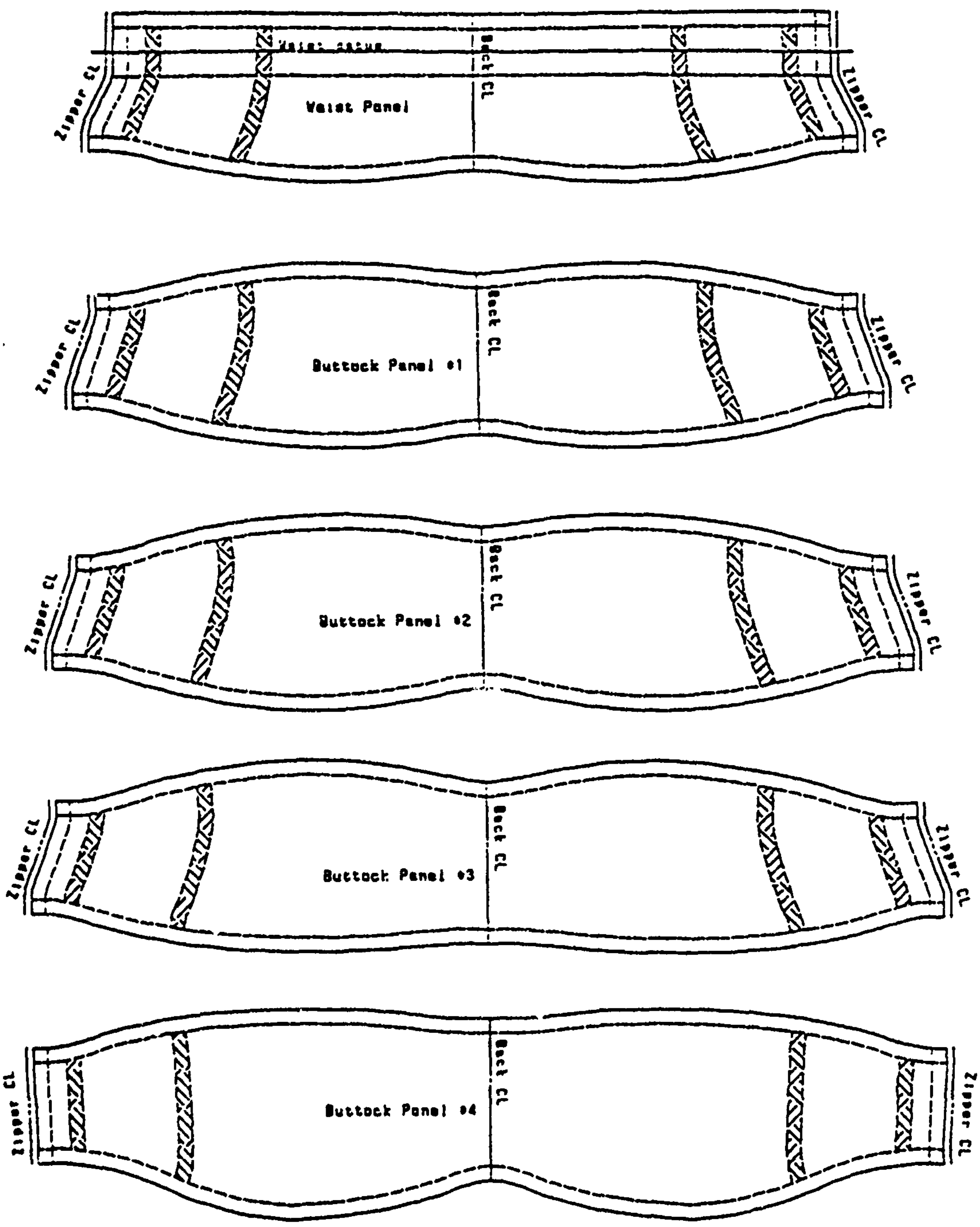
Front Restraint



Back Bladder

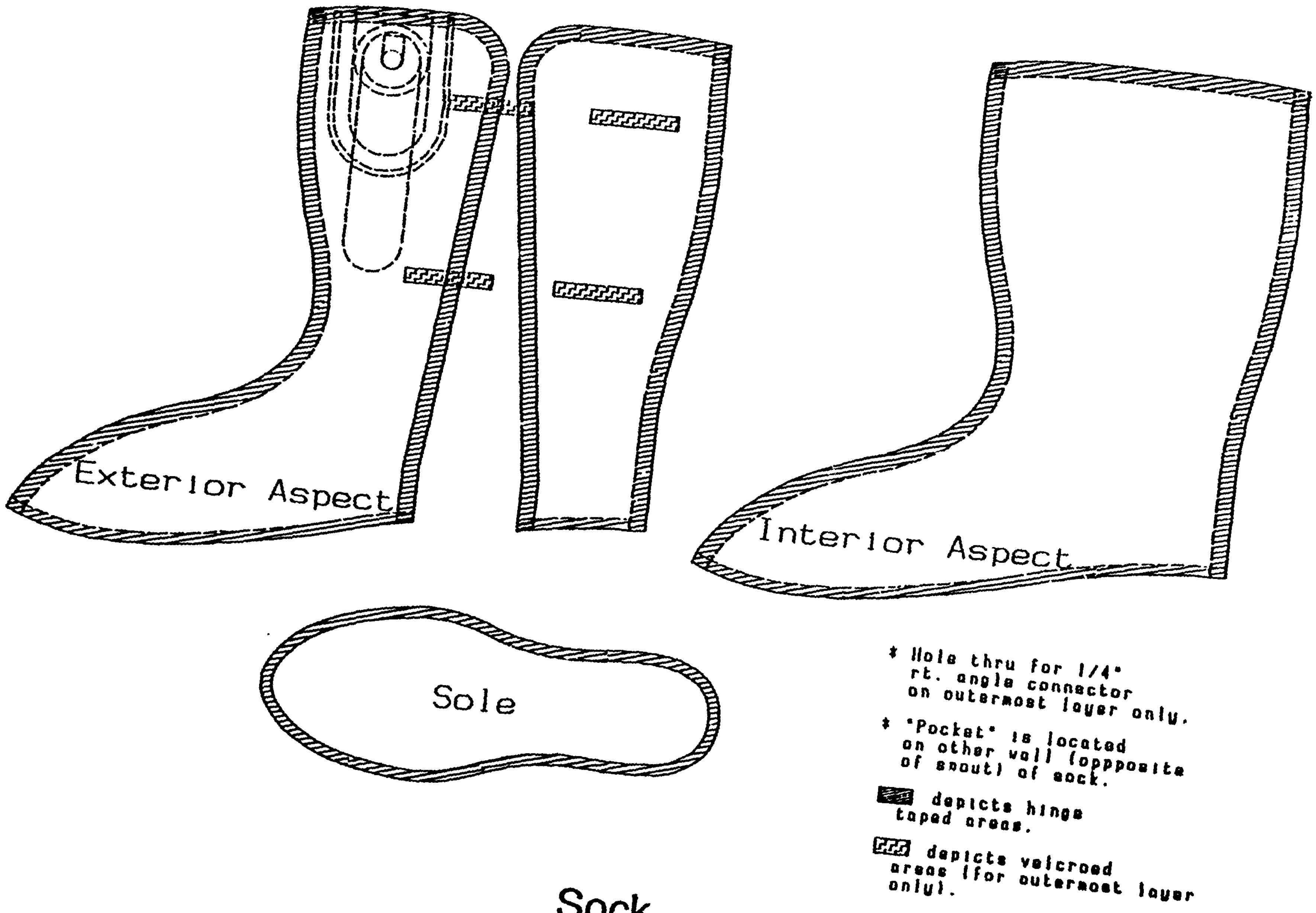


Back Restraint



location of lacing for waist and hip girth adjustment.

Waist and Buttock Panels


Exterior Aspect
Interior Aspect
Sole
* Hole thru for 1/4" rt. angle connector on outermost layer only.
* "Pocket" is located on other wall (oppposite of snout) of sock.
depicts hinge taped areas.
depicts velcroed areas (for outermost layer only).

Sock

APPENDIX C

ATAGS PATTERN DRAWING SCHEDULE

ATAGS PATTERN DRAWINGS SCHEDULE.

(a) UPPER FRONT LEG
(b) LOWER FRONT LEG
(c) UPPER BACK LEG
(d) LOWER BACK LEG
(e) BUTTOCK WAIST PANEL & BUTTOCK PANELS
(f) UPPER FRONT LEG
(g) LOWER FRONT LEG
(h) UPPER BACK LEG
(i) LOWER BACK LEG

ATAGS REF.No.	PATTERN DRAWING NOs.	
No. 05 & No. 12	(a) KRUG- 02-90-25	(f) KRUG- 02-90-30
	(b) “ “ -26	(g) “ “ -31
	(c) “ “ -27	(h) “ “ -32
	(d) “ “ -28	(i) “ “ -33
	(e) “ “ -29	
No. 06	(a) KRUG- 01-90-13	(f) KRUG- 01-90-18
	(b) “ “ -14	(g) “ “ -19
	(c) “ “ -15	(h) “ “ -20
	(d) “ “ -16	(i) “ “ -21
	(e) “ “ -5 & 17	
No. 07,08,09,10.	(a) KRUG- 02-90-36	(f) KRUG- 02-90-41 Issue2
	(b) “ “ -37	(g) “ “ -42 “
	(c) “ “ -38	(h) “ “ -43 “
	(d) “ “ -39	(i) “ “ -44 “
	(e) “ “ -40	
No. 11	(a) KRUG- 02-90-55	(f) KRUG- 02-90-60
	(b) “ “ -56	(g) “ “ -61
	(c) “ “ -57	(h) “ “ -62
	(d) “ “ -58	(i) “ “ -63
	(e) “ “ -59	

DETAIL	DRAWING No.
CONSTRUCTION DETAILS OF ABDOMEN BLADDER TIE WEB.	DRG No. KRUG - 02 - 90 - 70.

ATAGS PRESSURE SOCK PATTERN DRAWINGS.

	SOCK SIZE REFERENCE.	NOMINAL SUBJECT FOOT LENGTH.	DRAWING No.
*	'A'	8 1/2 in.	KRUG - 02 - 90 - 45.
*	'B'	9 in.	KRUG - 02 - 90 - 46.
	'C'	9 1/2 in.	KRUG - 02 - 90 - 47.
	'D'	10 in.	KRUG - 02 - 90 - 48.
	'E'	10 1/2 in.	KRUG - 02 - 90 - 49.
	'F'	11 in.	KRUG - 02 - 90 - 50.
	'G'	11 1/2 in.	KRUG - 02 - 90 - 51.
*	'H'	12 in.	KRUG - 02 - 90 - 52.

* NOTE: Drawing Nos. have been allocated for these sizes but patterns have not been produced.

APPENDIX D

ADVANCED TECHNOLOGY ANTI-G SUIT (ATAGS)
MATERIAL AND COMPONENTS SCHEDULE, ISSUE 1

ADVANCED TECHNOLOGY ANTI-G SUIT (ATAGS)
MATERIALS AND COMPONENTS SCHEDULE. ISSUE 1.

ITEM NO.	DESCRIPTION	PURPOSE/LOCATION	REFERENCE	QUANTITY	SPECIFICATIONS	MANUFACTURER/SUPPLIER
1	CLOTH, PLAIN WEAVE, NOMEX-4.3 OZ.	RESTRAINT LAYER CONSTR'N			MIL-C-83429 A	ARTHUR FORMAN ENTERPRISE LTD.
2	ADJUSTMENT LOOP TAPE	RESTRAINT LAYER ADJUSTMENT			MIL-W-81116	BALLY RIBBON MILLS
3	ADJUSTMENT LACING CORD	RESTRAINT LAYER ADJUSTMENT			MIL-C-83242	HOPE WEBBING CO.
4	ZIPPER - DON/DOFF	RESTRAINT LAYER		2	V-F-106E	TALON INC.
5	ZIPPER-FLY	RESTRAINT LAYER		1	V-F-106E	TALON INC.
6	HOOK & BAR FASTENER	RESTRAINT LAYER	PART NO. 166	4		ADJUSTA CO.
7	VELCRO-HOOK & LOOP	ADJUSTMENT COVER ASSEMBLY				VELCRO U.S.A., INC.
8	LACING COVERS CORD	ADJUSTMENT COVER ASSEMBLY			MIL-C-83242	HOPE WEBBING CO.
9	STIFFENER INSERT MATERIAL	RESTRAINT LAYER STIFFENER	PELON FABRIC			FABRIC WAREHOUSE
10	"DUTCH LACING" CORD	RESTRAINT/BLADDER ASSEMBLY			MIL-C-83242	HOPE WEBBING CO.
11	SEWING THREAD	RESTRAINT LAYER CONSTR'N			MIL-T-43636	SYNTHETIC THREAD CO.
12	CLOTH, NYLON, POLYURETHANE COATED - 6 OZ.	BLADDER & INITIAL SOCK CONSTR'N			MIL-C-83489	MANN INDUSTRIES
13	CLOTH, NYLON, POLYURETHANE COATED - 6.64 OZ.	ONLY R.H.F. WELDED BLADDER	LG 2032		BSF 127 FABRIC 6	GREENGATE POLYMER COATINGS LTD. MANCHESTER, U.K.
14	CLOTH, NYLON, POLYURETHANE COATED - 4.87 OZ.	SUPERSEDES ITEM 12 FOR SOCKS				GREENGATE POLYMER COATINGS LTD. MANCHESTER, U.K.
15	ADHESIVE - BOSTIK 7070-BASCOOR NO. 2	GLUED BLADDER & SOCK CONSTR'N				BESCO
16	ADHESIVE SOLVENT - MEK KETONE	GLUED BLADDER & SOCK CONSTR'N				SIGMA CHEMICAL CO.
17	MESH SPACER FABRIC	CONSTR'N OF SPACER MATERIAL	DS1			APEX MILLS CORP.
18	RETICULATED FOAM SPACER MATERIAL	ONLY ON R.H.F. WELDED BLADDER				DECLON LTD. CORBY, NORTHANTS, U.K.
19	MOLDED AIR ENTRY SPOUT	BLADDER		1		BEAUFORT AIR/SEA EQUIPMENT LTD. BIRKENHEAD, U.K.
20	AIR ENTRY SPOUT SLEEVE INSERT	BLADDER		1		KRUG LIFE SCIENCES
21	AIR ENTRY HOSE	BLADDER		1		R.E. DARLING CO., INC.
22	1/4" BORE ANGLED SPOUT	BLADDER & SOCKS		4		HALKEY ROBERTS, ST. PETERSBURG, FL.
23	1/4" BORE ANGLED SPOUT INSERT	BLADDER & SOCKS		4		KRUG LIFE SCIENCES
24	1/4" BORE TUBING	SOCK/BLADDER CONNECTION				MC MASTER-CARR SUPPLY
25	HOSE CLIP	AIR ENTRY HOSE/SPOUT INSERT		2		MFR. #06329
26	"0" CLIP	SOCK CONECTIONS		8		FLEXHOSE LTD., U.K.
27	COBEX (RIGID P.V.C.) COMFORT STRIP	PRESSURE SOCKS		1 PER SOCK		STOREYS IND. PRODUCTS, BRANTHAM, U.K.

APPENDIX E

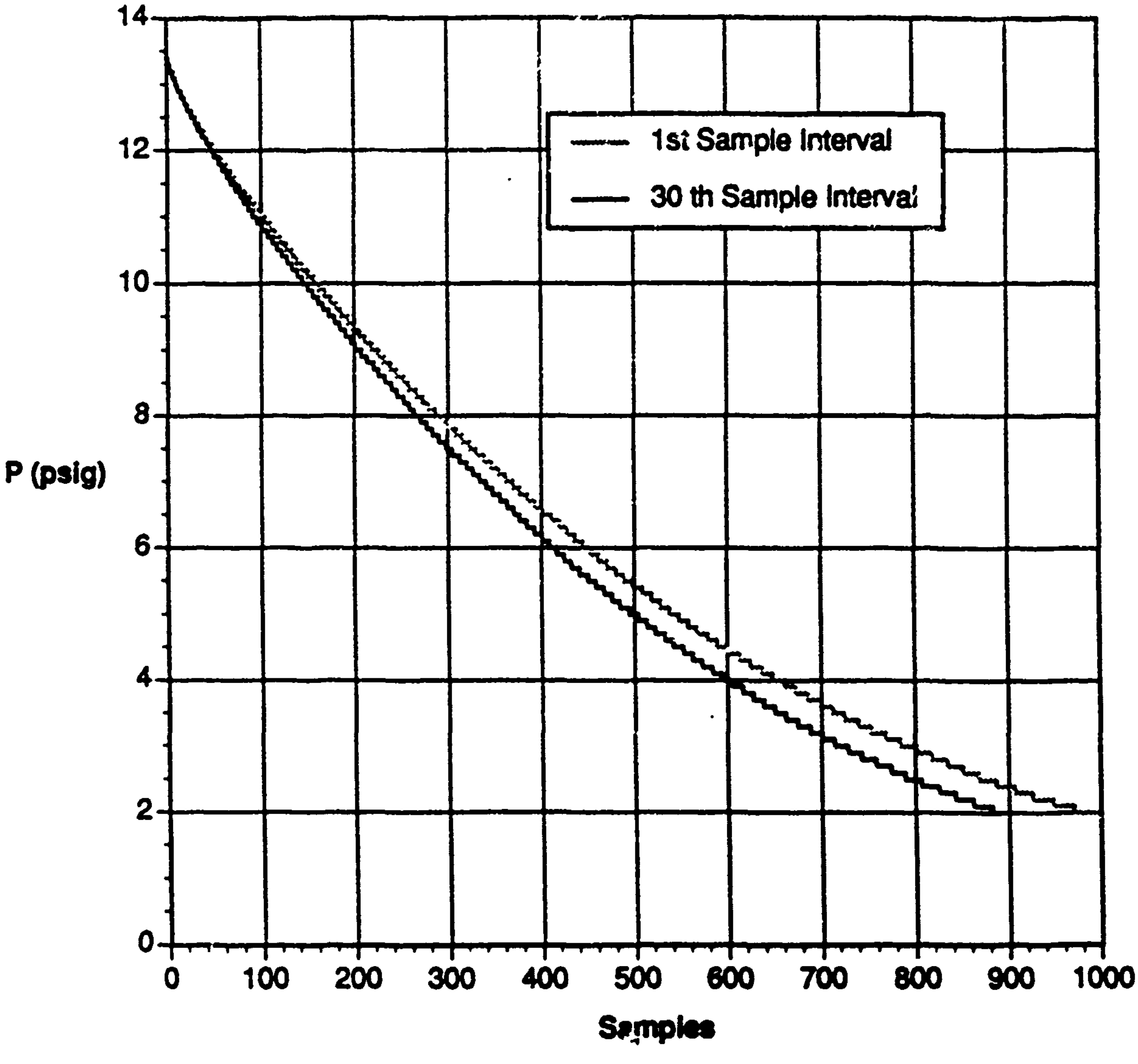
TYPICAL PRESSURE TEST RESULTS

TYPICAL DEFLATION RAW DATA

Size 2 Suit 6
Baseline test
Transducer @ 15 PSI
Infla HI @ 13.25 PSI
Defla LO @ 2 PSI

Cycle#	Sample#	Pressure (psig)
0	0	13.4
0	1	13.3
0	2	13.3
0	3	13.3
0	4	13.2
0	5	13.2
0	6	13.1
0	7	13.1
0	8	13.1
0	9	13.0
0	10	13.0
0	11	13.0
0	12	12.9
0	13	12.9
0	14	12.9
0	15	12.8
0	16	12.8
0	17	12.8
0	18	12.8
0	19	12.7
0	20	12.7
0	21	12.7
0	22	12.7
0	23	12.6
0	24	12.6
0	25	12.6
0	26	12.6
0	27	12.5
0	28	12.5
0	29	12.5
0	30	12.5
0	31	12.4
0	32	12.4
0	33	12.4

Pressure Response as a Function of Time Depicting the First and Last Pressure Intervals



APPENDIX F

EDWARDS FLIGHT TEST PROTOCOL - ATAGS EVALUATION

EDWARDS AFB FLIGHT TEST PROTOCOL - ATAGS EVALUATION.

NOTES

1. There is, as yet, insufficient accumulated data to evaluate whether genital clearance is adequate when the suit is pressurized for all combinations of man/garment fit. It would therefore be prudent for all flight test subjects to do a preflight press-to-test inflation of the ATAGS in the aircraft, prior to every flight.

2. Long underwear should be worn below the waist during flight appraisal of the ATAGS when evaluating the ATAGS under the flight suit.

3. Assessment of the ATAGS in-flight relief facility should be included in the test protocol.

4. Edwards AFB Flight Safety/Survival Section will require instruction on sock-change procedures and will need to be provided with spare sock-coupling components.

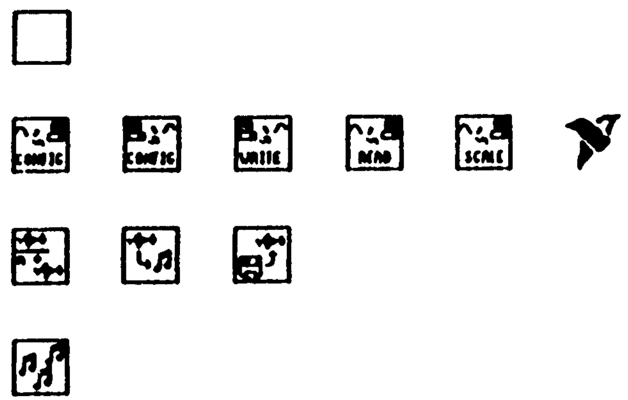
5. Some Edwards AFB test subjects may have to wear a larger-than-normal flight boot to accommodate the pressure sock. Donning the pressure sock may be eased by wearing nylon "Knee-highs" (folded over to boot top level) over the pressure socks.

APPENDIX G

ATAGS LAB VIEW LOGIC DIAGRAM

ATAGS Multi Cycle
Friday, April 5, 1991 11:50 AM

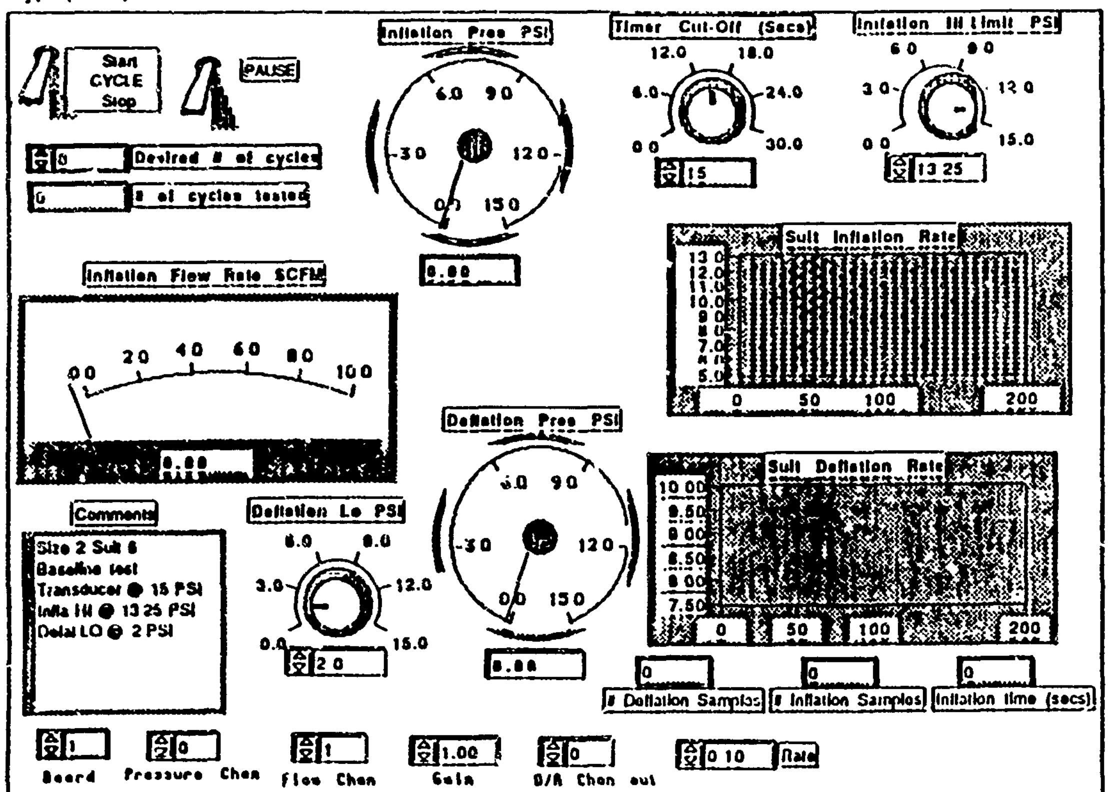
Position in hierarchy



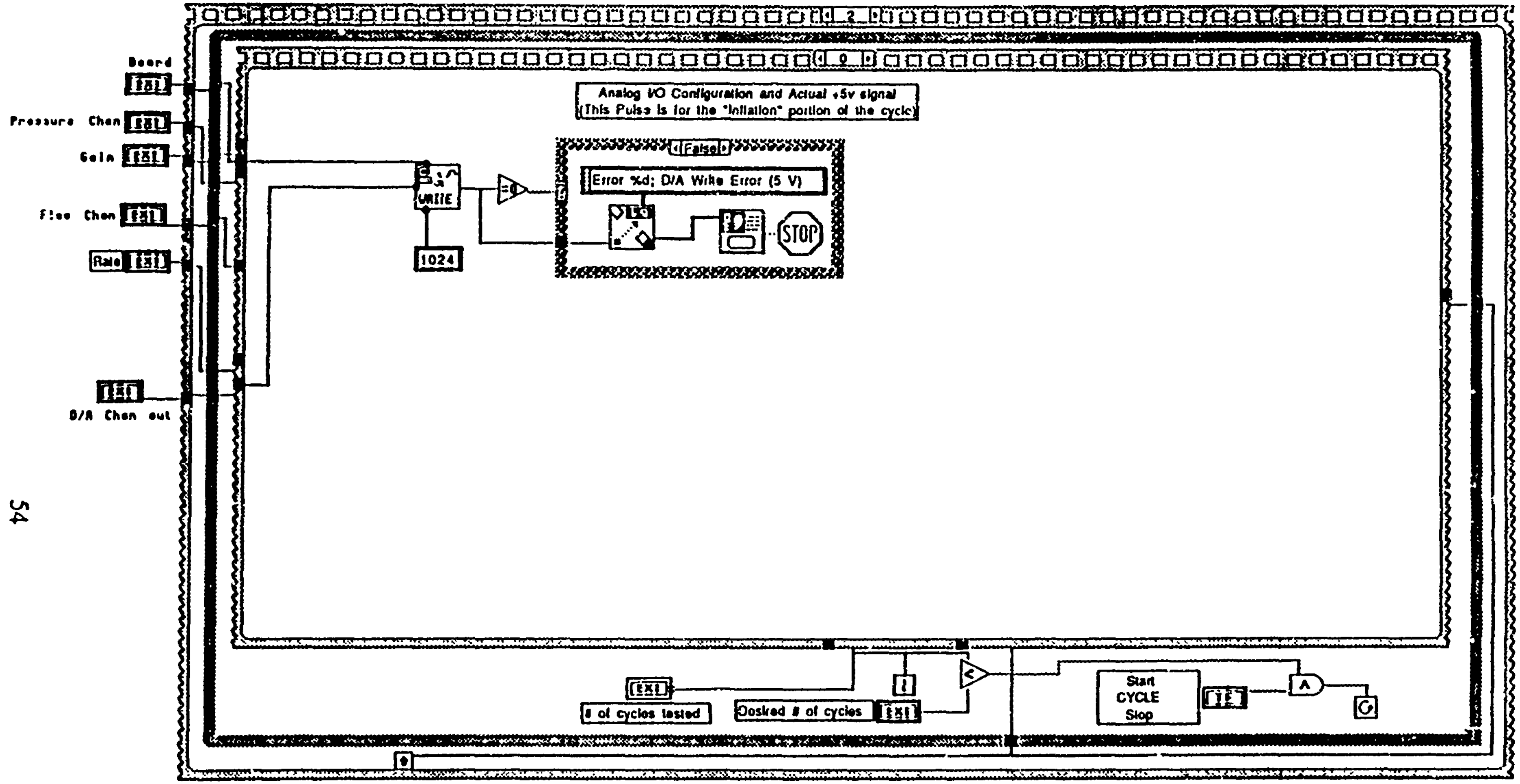
Connector Pane

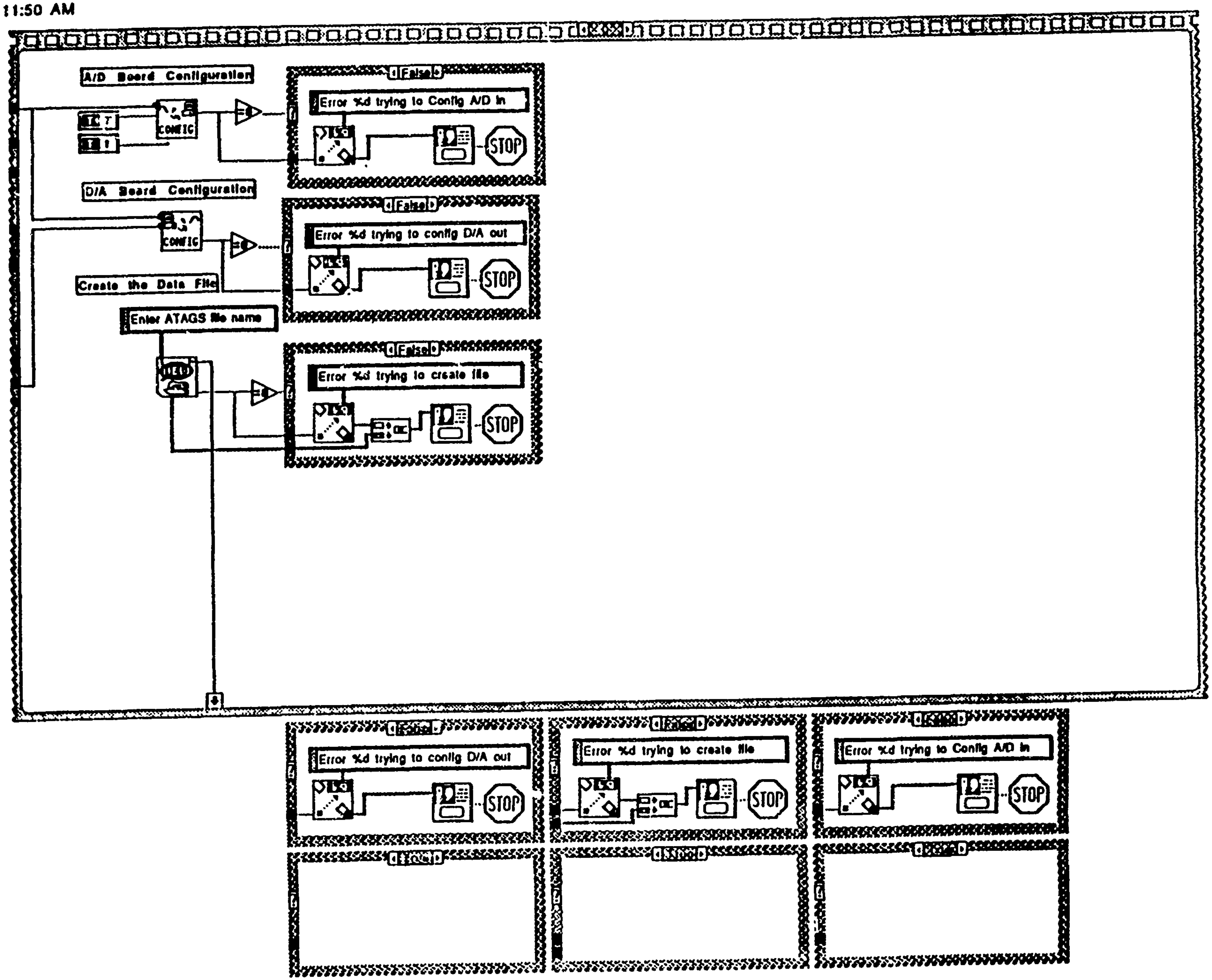
ATAGS Multi-Cycle

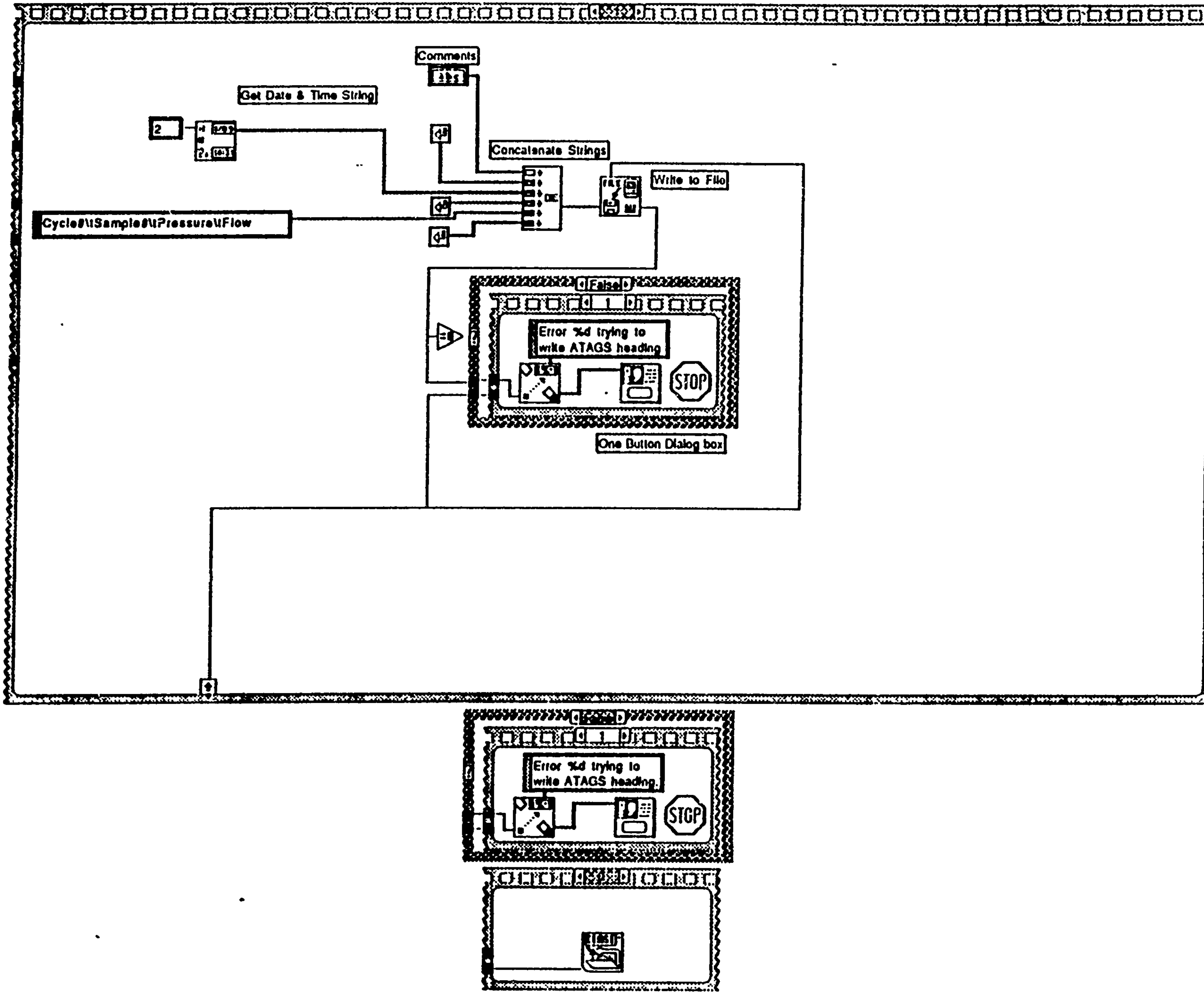
Front Panel

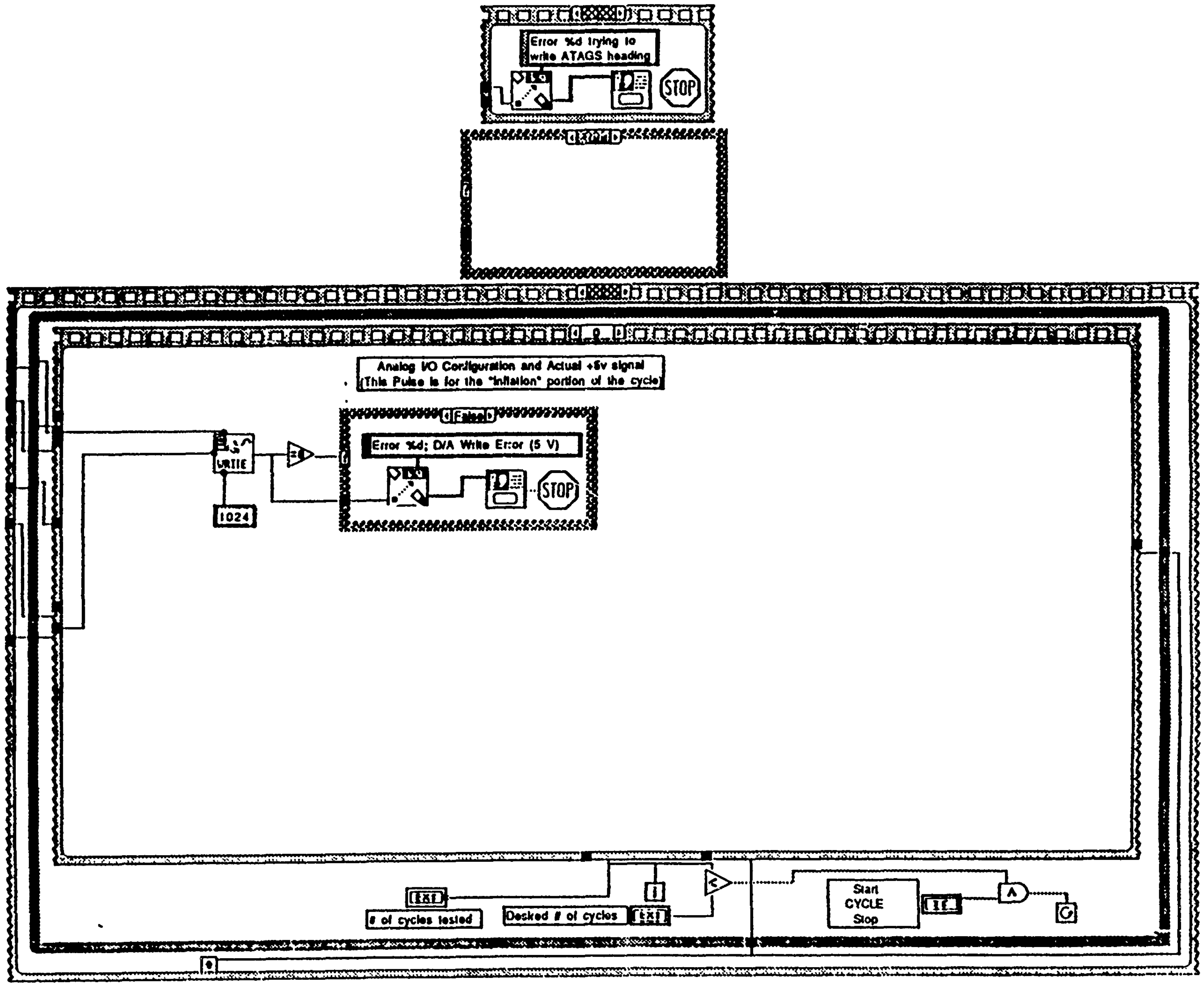


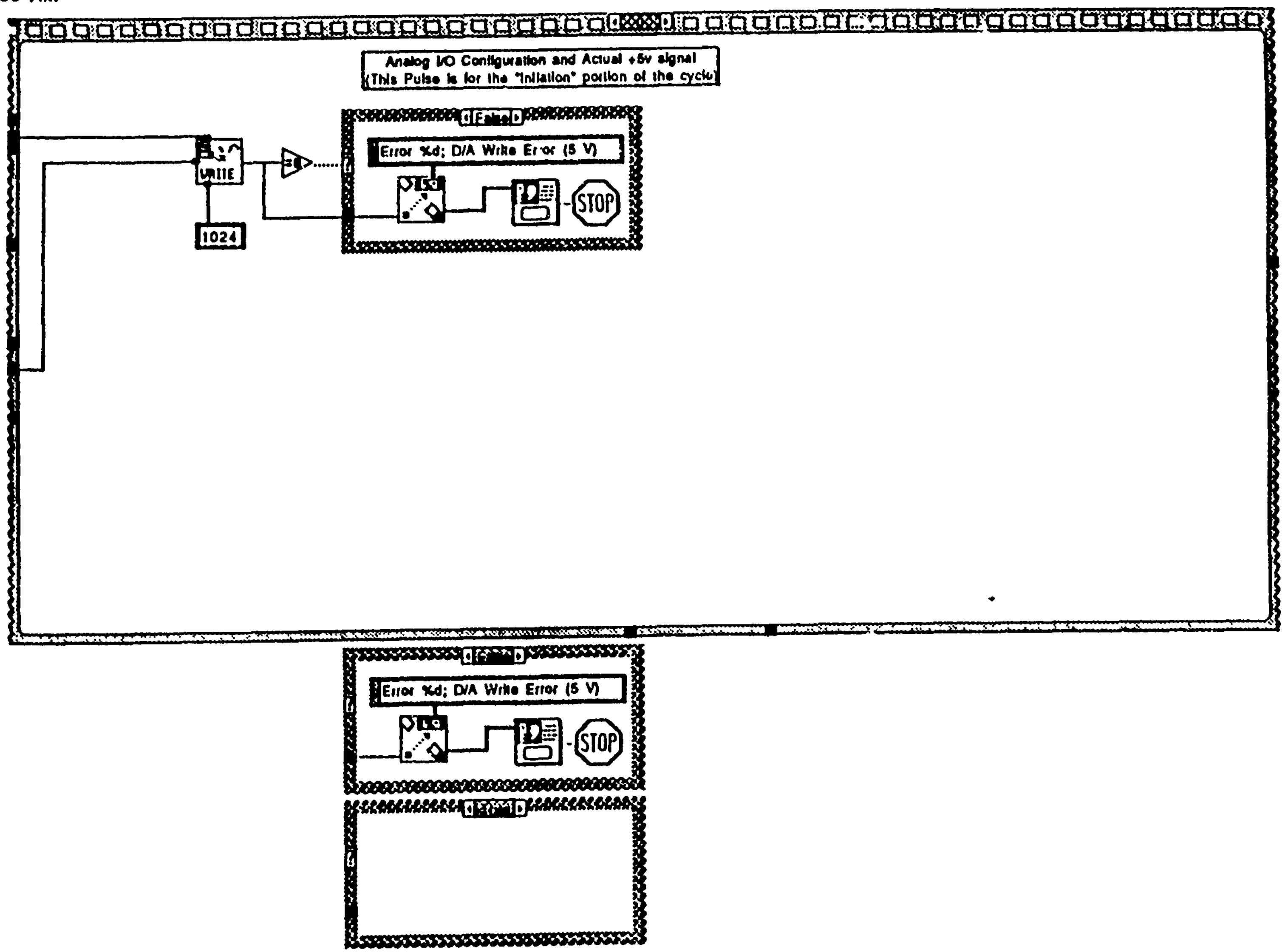
Block Diagram

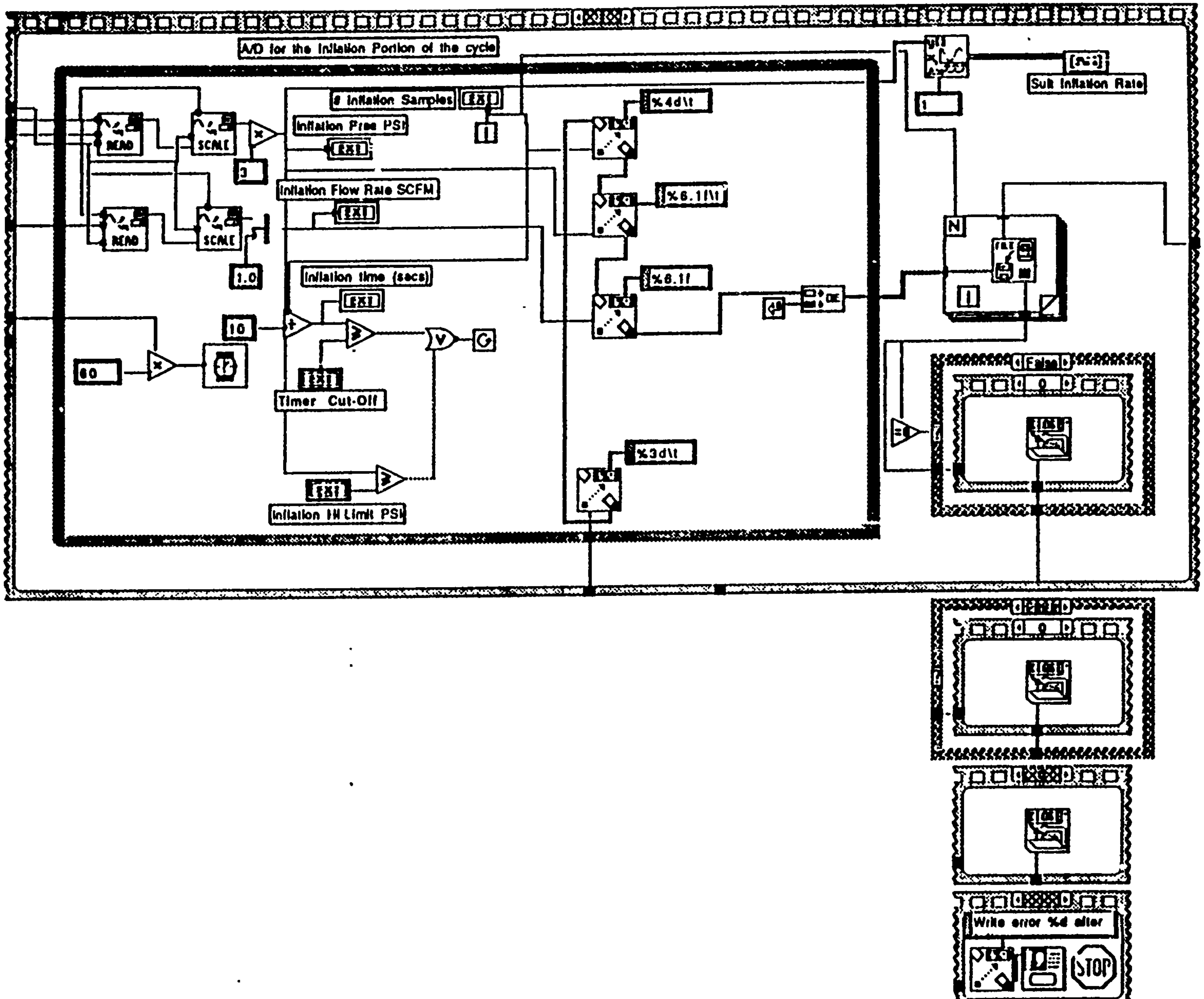

Board
Pressure Chan
Gain
Flow Chan
Rate
D/A Chan out
Analog I/O Configuration and Actual +5v signal
(This Pulse is for the "Inflation" portion of the cycle)
False
Error %d; D/A Write Error (5 V)
WRITE
1024
STOP
# of cycles tested
Desired # of cycles
Start
CYCLE
Stop

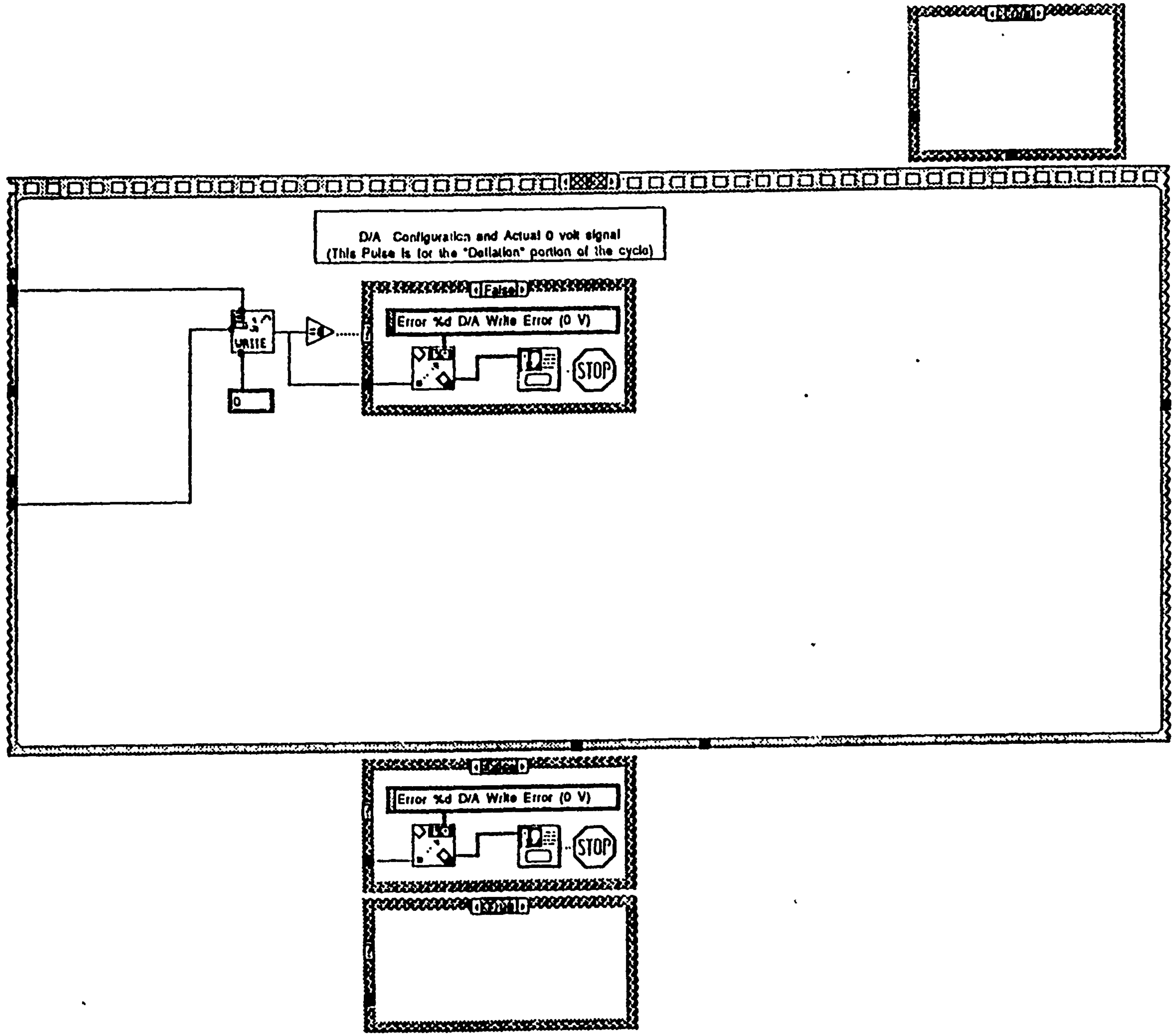

A/D Board Configuration
CONFIG
False
Error %d trying to Config A/D In
STOP
D/A Board Configuration
CONFIG
False
Error %d trying to config D/A out
STOP
Create the Data File
Enter ATAGS file name
False
Error %d trying to create file
STOP
Error %d trying to config D/A out
STOP
Error %d trying to create file
STOP
Error %d trying to Config A/D In
STOP

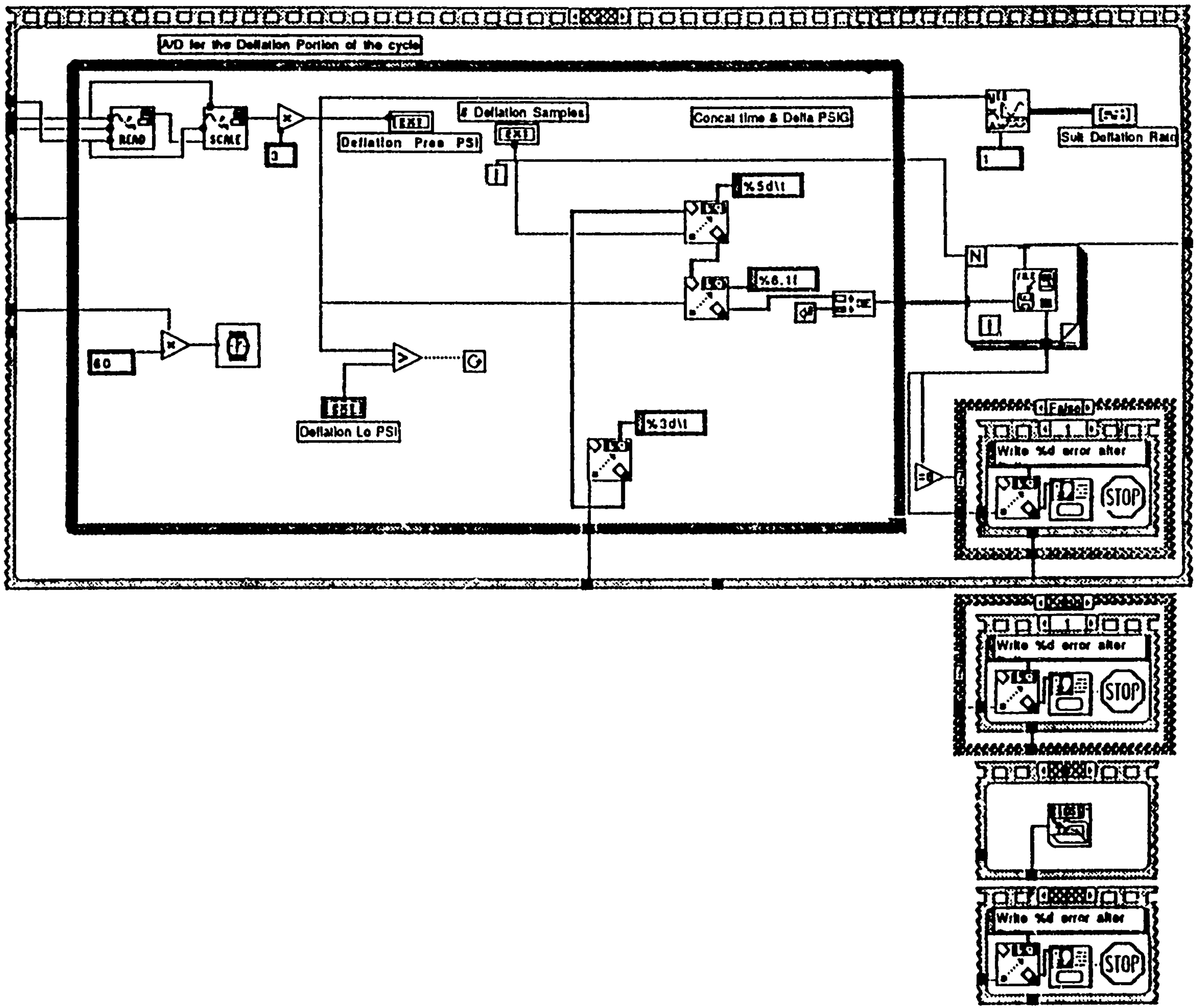

Comments
Get Date & Time String
2
Concatenate Strings
Write to File
Cycle#\tSample#\tPressure\tFlow
False
1
Error %d trying to write ATAGS heading
STOP
One Button Dialog box
1
Error %d trying to write ATAGS heading.
STOP

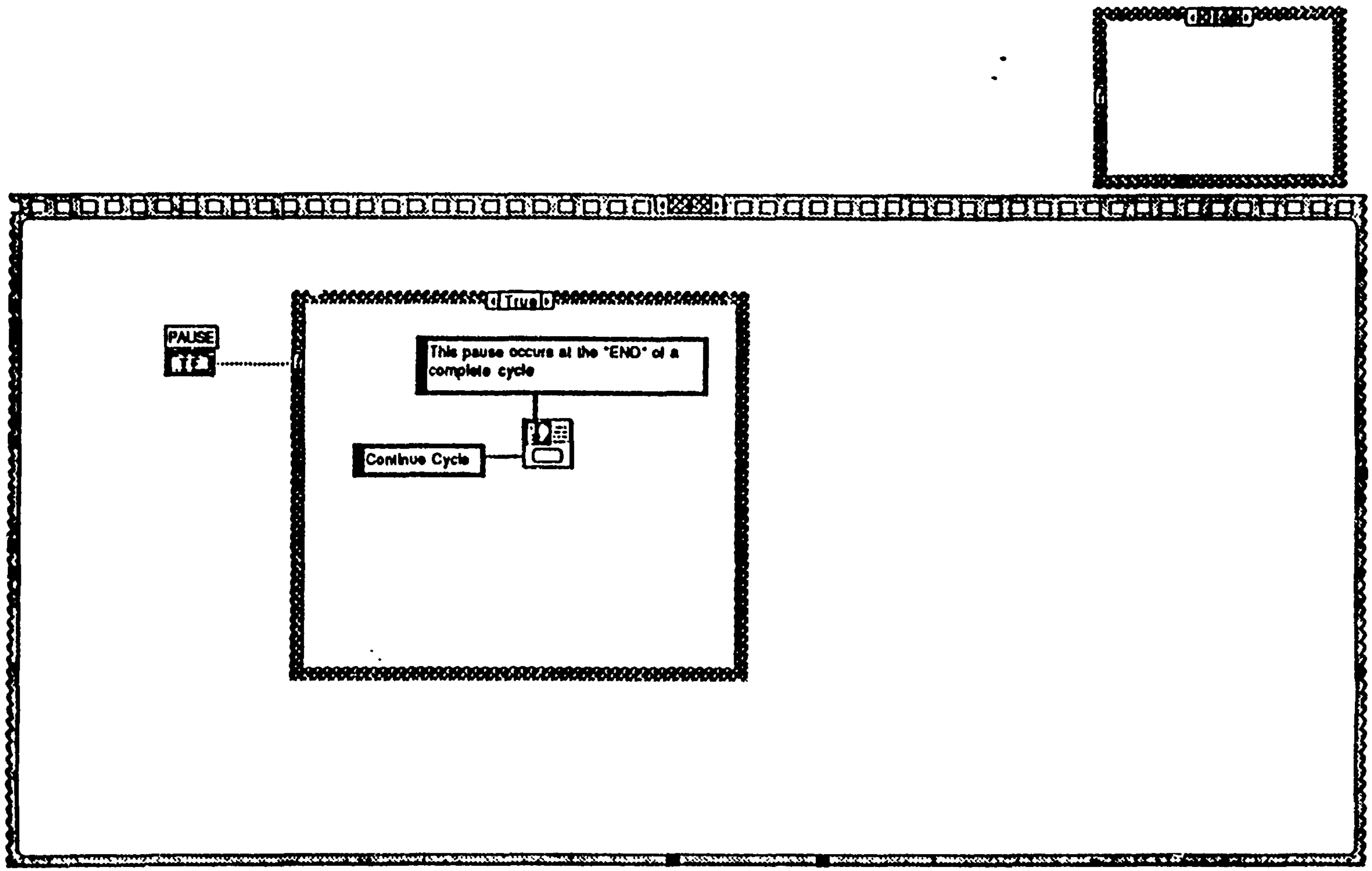

Error %d trying to write ATAGS heading
STOP
Analog I/O Configuration and Actual +5v signal
(This Pulse is for the "Inflation" portion of the cycle)
False
WRITE
1024
Error %d; D/A Write Error (5 V)
STOP
# of cycles tested
Desired # of cycles
Start
CYCLE
Stop

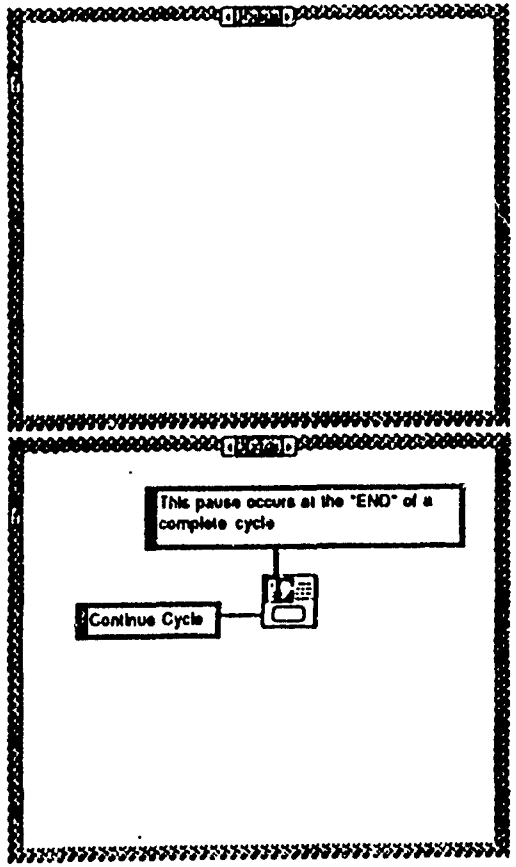

Analog I/O Configuration and Actual +5v signal
(This Pulse is for the "Initiation" portion of the cycle)
False
Error %d; D/A Write Error (5 V)
STOP
WRITE
1024
Error %d; D/A Write Error (5 V)
STOP

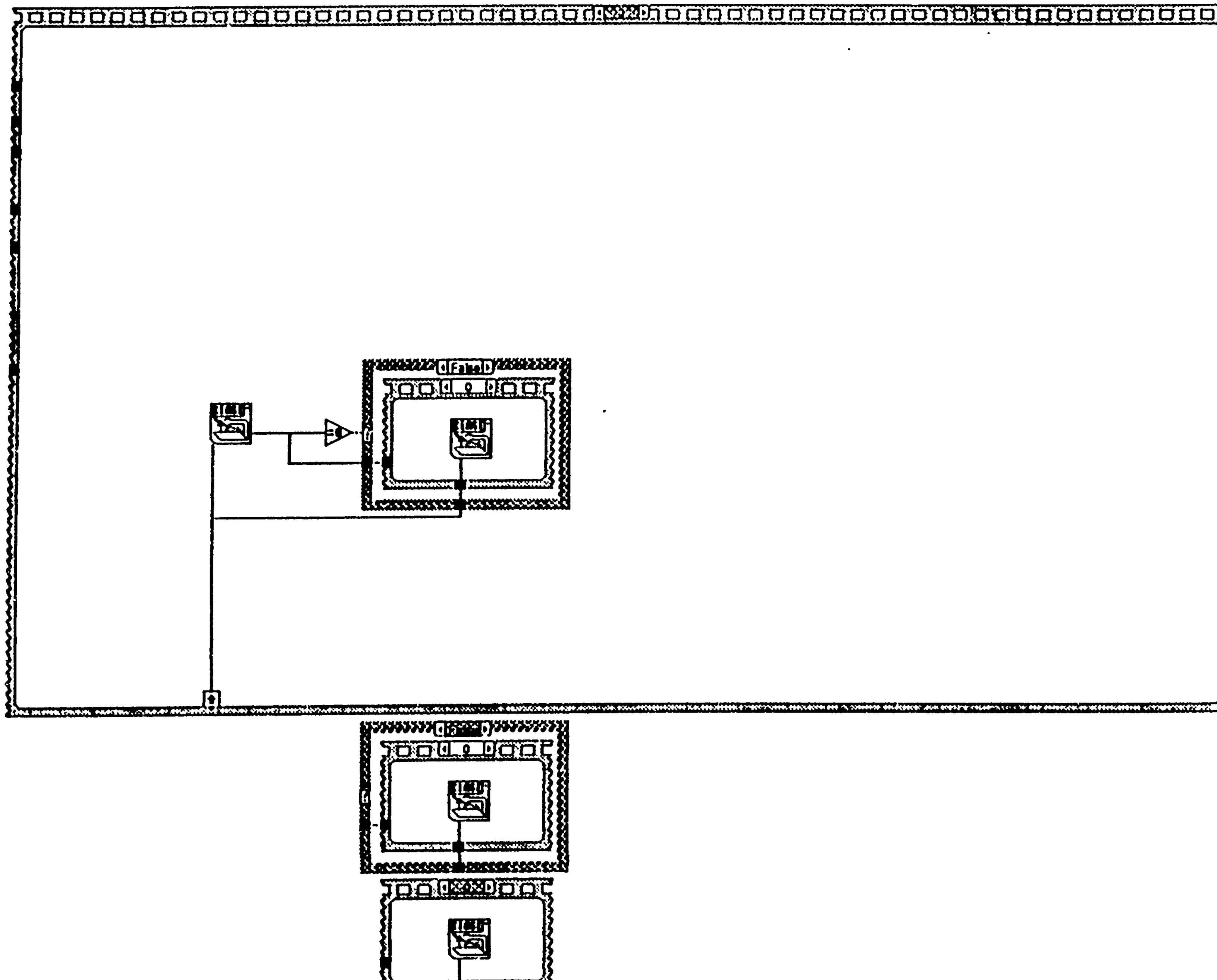

A/D for the Inflation Portion of the cycle
READ
SCALE
Inflation Samples
Inflation Pres PSI
Inflation Flow Rate SCFM
Inflation time (secs)
Timer Cut-Off
Inflation Hi Limit PSI
60
10
1.0
3
%4d\t
%6.1f\t
%6.1f
%3d\t
Sub Inflation Rate
N
False
0
Write error %d after
STOP

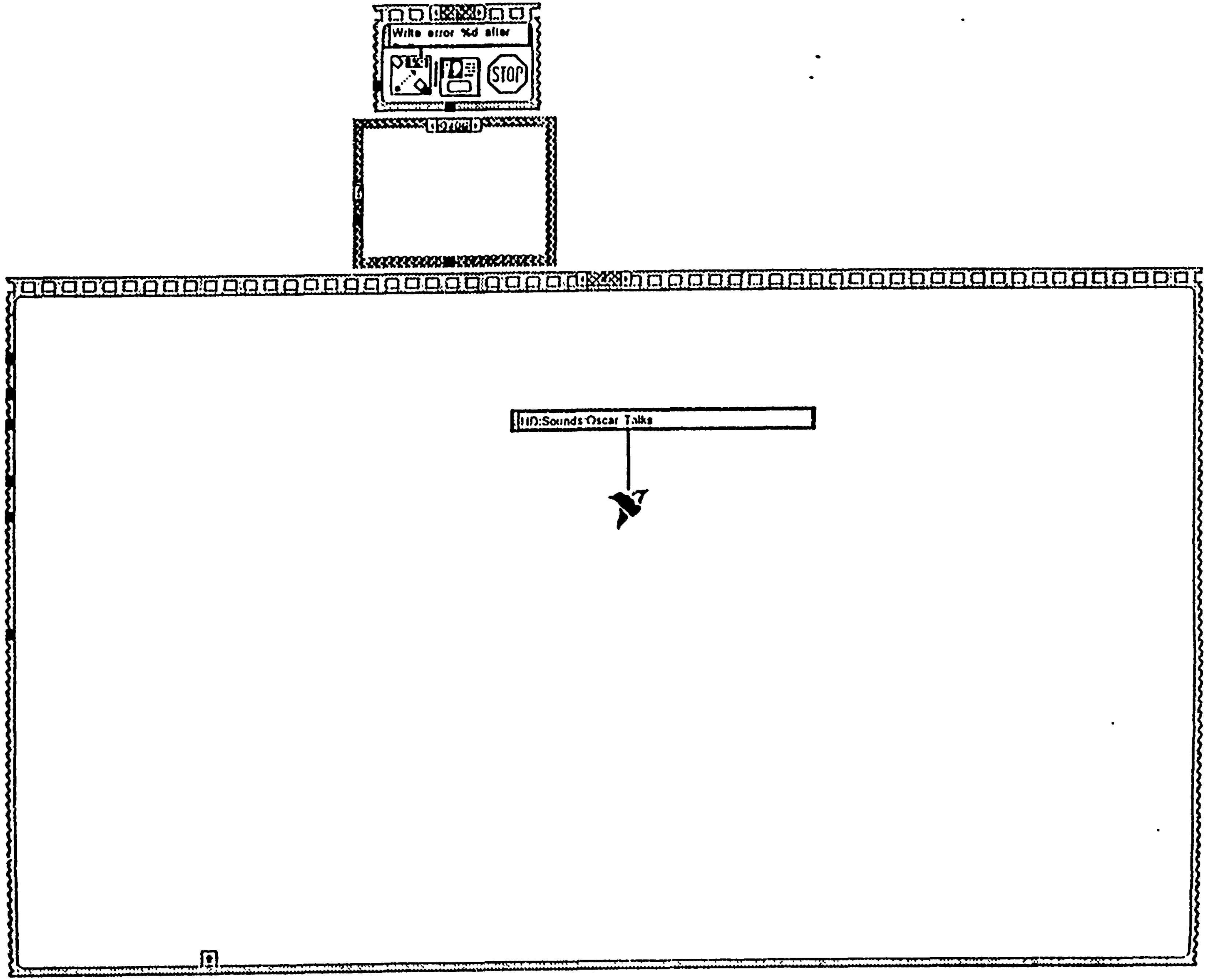

D/A Configuration and Actual 0 volt signal
(This Pulse is for the "Deflation" portion of the cycle)
False
Error %d D/A Write Error (0 V)
STOP
WRITE
0
Error %d D/A Write Error (0 V)
STOP


A/D for the Deflation Portion of the cycle
READ
SCALE
Deflation Pres PSI
Deflation Samples
Concat time & Delta PSIG
%5d\t
%6.1f
%3d\t
60
Deflation Lo PSI
Sult Deflation Rate
N
False
Write %d error after
STOP
Write %d error after
STOP
Write %d error after
STOP


True
PAUSE
TF
This pause occurs at the "END" of a complete cycle
Continue Cycle


This pause occurs at the "END" of a complete cycle
Continue Cycle


False
0


Write error %d after
STOP
HD:Sounds:Oscar Talks

DEPARTMENT OF THE AIR FORCE
ARMSTRONG LABORATORY (AFMC)
BROOKS AIR FORCE BASE TEXAS

ERRATA AD-B156796

FROM: AOPPS 22 Oct 93

SUBJ: Removal of Distribution Limitations

TO: DTIC-OCP

1. This letter serves as notification to remove all distribution limitations from USAFSAM-TR-90-32, Advanced Technology Anti-G Suit (ATAGS) Fabrication, December 1990, prepared under contract F33615-89-C-0603, AD B156 796.

2. This technical report was reviewed for release to the Canadian Embassy on 16 Apr 92. At that time, permission was given to remove distribution limitations; however, the report was never cleared through the Public Affairs office for release to the public (see attachment 1).

3. I was unaware of the request until recently; on 6 Oct 93, I contacted the contract monitor, Mr Larry Meeker, by telephone to verify removal of limitations; he was in agreement, and on 8 Oct 93 the document was cleared for public release (see attachment 2). Please change the distribution statement to: **Approved for public release;** distribution is unlimited.

4. For additional information, please contact Judy Bryant at DSN 240-4714 or (210) 536-4714.

Judy A. Bryant

JUDY A. BRYANT
STINFO Officer
Aerospace Medicine Directorate

2 Atch
1. DOKLS ltr, 16 Apr 92 and CFTF ltr, 9 Apr 92
2. USAFSAM-TR-90-32

151. 20/14

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