Proceedings of the Workshop on the Assessment of Crew Workload Measurement Methods, Techniques, and Procedures:
Part-Task Simulation Data Summary

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The air safety record has improved substantially in the decades since introduction of the jet transport in 1959 and throughout the period crew caused accidents dominated all other accident causes by a wide margin (Figure 1). It has consistently accounted for over 70% of the major (fatal or hull loss) accidents in spite of increasing attention to cockpit resource management programs and other human factors areas.

In 1986 we concluded a study of accident reports to better understand accident cause factors. A total of 126 major accidents which occurred worldwide during the period 1977 through 1984 were examined. From this group of accidents, 93 were identified where enough information was available to allow the determination of significant cause factors. The crew cause factor classifications and their percentage of presence in these 93 accidents are

![Figure 1. The distribution of causal factors in hull loss accidents between 1959-1985 as compared to 1976-1985 is depicted here.](image-url)
shown in Table 1. Effective control of these flight crew accident factors will depend largely on the airline operation and training community.

33% Pilot deviated from basic operational procedures.
26% Inadequate crosscheck by 2nd crew member.
9% Crews not conditioned for proper response during abnormal conditions.
6% Pilot did not recognize the need for go-around.
4% Pilot incapacitation.
4% Inadequate piloting skills.
3% Pilot used improper procedure during go-around.
3% Crew errors during training flights.
3% Pilot not trained to respond promptly to GPWS command.
3% Pilot unable to execute safe landing or go-around when runway sighting is lost below MDA or DH.
3% Operational procedures did not require use of available approach aids.
3% Captain inexperienced in aircraft type.

Table 1. Significant crew cause factors and percentage of presence in 93 major accidents.

Examination of worldwide accident history shows that some operators have more accidents than others. Using the Boeing fleet over a ten-year period as an example, 16% of the operators have crew caused accident rates higher than the fleet average and these operators account for over 80% of the total accidents. Conversely, 80% of the operators had no crew caused accidents over the same period. The distribution of accidents for the fleet is shown in Figure 2.

Figure 2. The distribution of crew caused accidents involving operators of Boeing airplanes between 1975-1984.

Boeing recently contacted a small group of operators, most of which had better than average crew caused accident history. This was done with a view to obtaining information on techniques which contribute to safe operations and which could be brought to the attention of all operators through our Flight Operations Support Program (FOSP) where we provide pilot-to-pilot contact with the operators. Over a two-year period 12 operators were contacted. Meetings with management pilots in the flight operations and training departments focused on what was considered by the operators to be key elements of safe operation. It is the results of these informal meetings that are summarized here. To avoid repetitious qualifying phrases denoting the degree of consensus on any point the reader may assume a reasonable consensus unless the individuality of the comment is emphasized. The findings are grouped for convenience of presentation only. The format does not imply a structured approach to the discussions held with the operators.

Management Emphasis on Safety

In the broad context of management these operators characterize safety as beginning at the top of the organization with a strong emphasis on safety and this permeates the entire operation. Flight operations and training managers recognize their responsibility to flight safety and are dedicated to creating and enforcing safety-oriented policies. The presence or absence of a safety organization did not alter the total involvement of these managers. However, a majority of the operators did maintain an identifiable flight safety focal point. There is an acute awareness of the factors that result in accidents, and management reviews accidents and incidents in their own airline and in other airlines and alters their policies and procedures to best guard against recurrence. There is a method for getting information to the flight crews expeditiously and a policy that encourages confidential feedback from pilots to management. This management attitude, while somewhat difficult to describe, is a dynamic force that sets the stage for standardization and discipline in the cockpit brought about and reinforced by a training program oriented to safety issues.

Standardization and Discipline

Management recognizes the need for aircrews performing in a standardized way and the importance of cockpit discipline in providing the environment for proper crew coordination. This results in a number of specific policy implementations:

- A standardization pilot and a standardization flight engineer (if applicable) are appointed, usually one for each type airplane in the fleet. All procedure and checklist issues are coordinated by the standardization personnel recognizing differences in airplane and cockpit configuration within the type.
A strong check airman program acts as a continuous quality control check on the training department. Standards for check airman candidates exist in writing and the highest level of flight operations management participates in the evaluation and selection process. Methods exist for assuring the uniformity of check pilot techniques and instruction, usually accomplished during periodic (monthly) meetings of all check pilots. There is a special system of recurrent checks for check pilots that is independent of the line pilot recurrent training program. An effort is made to assure the uniformity of checking techniques by correlating reported non-standard behavior in students to individual check pilots where possible.

There is a firm requirement for in-depth takeoff and approach briefings for each flight segment. This provides the entire crew with knowledge of precisely how the event is to be performed. The takeoff briefing is a review of departure plans, rejected takeoff (RTO) technique, and contingency plans in the event of an emergency calling for return to the departure airport. One operator requires an RTO touch drill where each control used during RTO is sequentially touched by the pilot who will be making the takeoff.

The approach briefing is usually done at the top of descent before workload increases. It covers the navigation, communication and procedural details of the approach for the specific runway involved, including missed approach details.

Cockpit procedural language is tightly controlled to maintain consistency and to avoid confusion from non-standard callouts which can result from crew members using differing phraseology. Callouts and responses are done verbatim. The recurrent training program and check pilot system rigidly enforce this requirement.

The large operators, operating several airplane types (often of more than one manufacturer) devote a good deal of effort to standardize checklists and operations manuals to meet their operational philosophy and format. A few feel that cockpit configuration standardization is essential and that the money is well spent to keep cockpits as nearly alike as possible.

All operators surveyed prefer accomplishing their own training so that positive control of standardization and discipline can be maintained. About half provide training for other operators. They voiced concern that in order to cut costs, buyers of training will request a training program less extensive than the seller uses to train his own crews and noted the difficulties this imposed on training contract negotiations. Of course where the seller leases unmanned facilities to a buyer who provides the training personnel the seller loses any say in the quality of training.

It was also felt that airlines that buy training from the lowest bidder may experience a lack of standardization. This results from the fact that: 1) New-hire rated pilots may not receive complete coverage of company philosophy and procedures, 2) Initial and recurrent training may not be bought from the same source and 3) The source of recurrent training may change from time to time. Too often the airlines we visited who perform contract training see a crew arrive for training where each pilot’s prior training has been with a different contractor. Sometimes the pilots even have different operating manuals which were obtained during their respective training programs. These types of problems make it difficult to attain a satisfactory level of standardization, communication and smooth performance as an integrated crew.

The on-site availability of full-flight simulation is a tremendous boost to conducting a high quality flight crew training program. With the exception of one or two airplane types where fleet size would clearly not justify the expense of dedicated simulators the operators visited often stretched themselves financially to have a full flight simulator for each type in the fleet. In the few cases where the simulators were not owned the operators leased simulators and provided the instructors from their own ranks. For the 12 operators the simulator types owned as a percentage of fleet airplane types was 90%. As a matter of comparison the operators who have worse than average accident rates have only a 60% coverage of the fleet with company-owned simulators.

Recurrent Training

The criticality of recurrent training to continued safe operation is universally recognized. Many of the issues discussed in other sections of this article are implemented through a training program that recognizes and provides emphasis on accident related operational topics such as windshear, ground proximity warning system (GPWS), rejected takeoff and human factors.

All operators stressed the importance of a well managed and thorough recurrent training program. Most of the operators surveyed train captains and first officers to the same standards and provide the same quality and quantity of training to both. Half of the operators also type-rate all pilots to the same standards. A few provide simulator training four times per year. One operator who had established a standard of four recurrent training sessions per-year per-crew attempted to cut training costs by
reducing the training sessions to two per-year for crew members who were located at a remote domicile. After a trial program this operator reverted to the basic four sessions per year based on a noticeable degradation of piloting skills in the two-per-year crews. This skill loss was particularly noticeable for the lower 20 percent of the pilots.

Firm rules exist and are enforced if poor performance is noted in training. No flying is permitted until satisfactory performance is demonstrated. If problems persist, high level management faces up to the tough decisions of alternate assignments, demotion or dismissal.

Several operators regularly cycle training captains through a line-flying period to keep them in touch with actual operations.

**Flight Path Control**

Since the approach and landing phase accidents comprise such a large segment of the total accident picture (Figure 3) it is not surprising that we found much emphasis being placed on the stabilized approach and proper energy management. It is felt that reduced flap settings and late gear extension brought about by fuel conservation measures contribute to destabilized approaches. The more modern, aerodynamically clean, airplanes can pose problems for a crew that does not plan the approach sufficiently in advance. Speed and altitude can be difficult to bleed off if the ideal approach path is overshot and/or airspeed is too high. Higher thrust settings for engine anti-ice, if required, make matters that much worse. ATC often can place the airplane close-in and high and, if the crew is not alert, the speed which must be dissipated may preclude attaining a stabilized landing configuration at a reasonable altitude. If the approach is not stabilized it is more difficult to detect the effects of windshear and in fact any changing wind conditions. When the approach becomes hurried normal monitoring and crew coordination are subject to breakdown and the stage is set for a landing accident. Management and training emphasis was found in the following areas:

- There are firm rules for flap and gear extension versus altitude. There is often a cutoff altitude specified where, if the airplane is not on glide path in landing configuration with speed stabilized, a go-around is mandatory. These altitude gates are usually different for instrument and visual conditions.

As an example, one operator who places stringent management controls on approach techniques begins with the simulator phase of transition training. Parameters for control of the approach must be committed to memory. For given landing configurations the approximate attitude, thrust setting and vertical speed targets are committed to memory and applied so that the following rules for the approach can be met:

1. The airplane should be stabilized in landing configuration by 1000 feet above touchdown. If there is significant crosswind, low clouds or poor visibility then the airplane should be stabilized at least the outer marker.

2. It must be stabilized by 500 feet and if not, an immediate missed approach must be initiated.

- There is a requirement for monitoring instruments including approach displays during visual approaches. One operator has a policy that whenever landing aids are available every approach is an instrument approach. Operational procedures and training reinforce the philosophy that the ability to see the ground is just an additional landing aid.

- The infrequent occurrence of the visual missed approach seemed statistically unreasonable to some operators and prompted them to emphasize the go-around decision in training, remove the requirement to report go-arounds to management, and develop procedures which encourage the crew to make a go-around rather than attempt a landing out of a poor approach.

- One operator felt that early training (primarily military) over-emphasized the skills for a complete power-off approach and diminished attention to proper approach techniques.
First Officer Flying Rules

Some operators believe that captains do not always do the monitor functions well when the first officer is flying. This problem receives special training emphasis, to demonstrate that the captain in this circumstance really must perform all the first officer duties in addition to his pilot-in-command functions. (To better understand the individual crew member's involvement in this problem, Boeing studied crew caused accident history where it could be determined which pilot was handling the airplane. It was found that in a majority of the accidents the non flying pilot (NFP) had the opportunity to effect corrective action but failed to do so. However, the captain did not appear to be an ineffective NFP when compared to the first officer.)

There are usually specific rules governing when the captain must make the approach and landing. These vary widely from operator to operator but many had rules more specific than Captain's choice or alternate legs. These rules which specifically call for the captain to handle the airplane fall into four general categories:

- Airports that have geographic hazards or congestion problems.
- Weather minimums - most frequently below 1200 RVR or for Category II and III landings.
- When there is a primary airplane system malfunction.
- Low first officer time in type.

One operator determined that ground handling accidents and incidents were more frequent when the first officer was taxiing. A rule was adopted that requires the captain to taxi.

Line Oriented Flight Training (LOFT)

LOFT was fully implemented in the recurrent training program for nine of the operators and partially implemented at two. Those operators who use LOFT were of the opinion that this training element is a very important safety enhancement. It provides a method of exposing a crew to a complete flight operation (such as preflight operations, the flight itself and the postflight activity) in such a way that company procedures, flight procedures, flying techniques and cockpit management (human factors) are observed without providing any more assistance to the crew than it would have on a real flight. Crew operating and teamwork shortcomings are reviewed in a debriefing by a training pilot. Some airlines have introduced video recording playback into the debriefing and found this beneficial in allowing self-critique by the pilots.

Thoughtful preparation of LOFT scenarios is essential in order to provide a maximum of crew decisions, actions and opportunity for error in a realistic flight that has an abundance of high crew workload and stress. Some operators see a need for more realistic scenarios with less emphasis on multiple failures in non-critical phases of flight and more emphasis on realistic situations in the approach and landing phases. Creating enough scenarios to adequately cover the training objectives and to prevent crew familiarity through repetition was a frequently mentioned problem.

Reference Data

Some operators are concerned that automated dispatch, computerized airport analysis and flight planning although considered essential in today's operation may reduce the pilots' familiarity with the performance capability of the airplane. One operator is increasing emphasis on this aspect in the training program.

More on Management

The key safety elements discussed so far were recognized by management as significant safety concerns upon which they placed almost universal emphasis in each of their respective flight training programs. The items below are more random in nature and do not lend themselves to catagorization but they too fit the mold of key elements.

- Flight data recorder monitoring is being practiced by 3 of the 12 operators primarily as a tool to provide direction to the training department. The digital recorder tapes for each flight are compared by computer against predetermined standards for specific flight phases. Substantial deviation from standards such as early rotation, high descent rate, unstabilized approach and high touchdown speeds are automatically identified for further investigation. The operators who have implemented this system are very enthusiastic about its contribution to safety and have found ways to structure the program so that flight crew concerns are addressed and their support is obtained. Taking a serious flight-related event to the specific flight crew for review is done through the Association representative in the few instances it is required, but this aspect is considered of far less significance in comparison to the benefits derived in understanding where operational procedures and or the training program might need modification or emphasis.

- All operators have firm policies requiring immediate pull-up in response to a ground proximity warning in Instrument Meteorological Conditions (IMC) but only two investigate each case in order to determine the cause and verify that a proper response was made. Most operators express concern that unreliability of the early GPWS is still influencing some pilots to delay pull-up instead of initiating an immediate response. Several operators have already implemented GPWS response training in their simulator programs.
- Pilots are being made more aware of the significance of \( V_1 \) and the practical aspects related to aborting or continuing a takeoff. The criticality of actions to stop or to go when airplane speed is in the vicinity of \( V_1 \) is becoming better understood by the flight crews in these airlines.

- Problem airports receive careful analysis and management attention; special training, experience and currency requirements are laid down. The method of handling this problem varies from operator to operator. As an example one operator classifies all airports of interest into three categories and specifies certain landing requirements for each category. These are:
  1. Standard – all captains are qualified.
  2. Operational problems – 24 months with the airline as captain or prior operation into the airport as pilot or observer.
  3. Non-standard – as pilot or observer within last 12 months. In addition a number of the non-standard airports have more stringent requirements. One, for example includes:
     - First checkout with a training pilot
     - At least 5 takeoffs and landings before revenue flight
     - Minimum of 2 approaches, landings and takeoffs within the last 2 months
     - Landing by captain only
     - Night checkout prior to night operations

Where do we go from here?

The results of this limited study indicate that the potential for improvement of the crew caused accident rate may be great if some key policies, procedures and practices are adopted and followed. Figure 4 shows that this improvement might approach a factor of ten for the worldwide fleet if the rate for the 12 operators is statistically valid. A review of the nearly 350 Boeing operators shows that at least 54 have accident rates worse than average and therefore might benefit from a close look at their own standards, discipline, procedures and flight crew training programs (Figure 5). Boeing will continue to investigate and expand its knowledge of crew caused accidents and communicate any findings to the operators.

To summarize, we are unable to prioritize the findings of this study since every aspect is important. However, the low crew caused accident carriers seem to have found the key to integrating the elements into a successful operation.

Our sincere thanks go to the 38 management pilots of the 12 airlines that gave so generously of their time and talents to make this first step possible. Comments from readers of this article, particularly more Key Elements for safe operation, would be most welcome. Please write to:

Boeing Commercial Airplane Co.
Attn: Safety Manager M/S 98-33
P.O. Box 3707
Seattle, WA 98124

Flight operations and training managers who are willing to provide details of their airline's operation in order to broaden the scope of this study may request a copy of a questionnaire developed for this purpose.

Figure 4. The jet transport accident rates for three classes of accidents occurring between 1975-1984 are compared in this illustration.

Figure 5. Crew caused accidents within the Boeing Fleet between 1975-1984.
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*PCNL: Pre-CrashNightLine*
Proceedings of Workshop on the Assessment of Crew Workload Measurement Methods, Techniques, and Procedures: Part-Task Simulation Data Summary

Supported in part by FAA

Subjective measures, Performance measures, Physiological measures

Proceeding of a two day workshop to review the results of a part-task simulation program to determine the validity, reliability and applicability of candidate workload measurement techniques intended for use during aircraft certification.

Keywords:
During the second Workload Workshop, held in Seattle during September, various data collected during our PART-Task simulation was presented. Data was presented for the Subjective Workload Assessment Technique (SWAT) and the NASA Task Load Index (TLX) which contained some errors. The following proceedings contains the correct data, and data analyses for both validity and reliability. None of the discriminability analyses outcomes changed for the correct data. The ability to discriminate LOW and HIGH workload remained the same, as well as the discrimination among individual "windows" of measurement and discrimination among phases of flight within LOW and HIGH workload, respectively. The reliability test/retest data was affected significantly by the analyses done with the correct data. SWAT, which did not appear to be very reliable from one session to the next, turned out to be nearly as reliable as the NASA-TLX data. TLX reliability coefficients slipped very slightly with the analyses redone with the correct data. The two measures, SWAT and TLX, appear to be more similar than originally presented at the Seattle workshop.
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Appreciation is also expressed to Mariel Sipman and David Nixon for their efforts during the data reduction and analyses of the PART-Task simulation data.

The Editors would also like to express their appreciation to Nancy Whitman for her efforts in coordinating hotel and catering arrangements and her on-site support during the workshop; Janet Camarata and Marji Yates for their efforts in preparation of the workshop documentation; and Gary Boley and Dan McGehee for their assistance during the workshop program.
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INTRODUCTION

Currently, The Boeing Company and Douglas Aircraft Company are jointly working a USAF/FAA sponsored workload contract. The objective of this contract is to provide guidelines for a flexible basis for selecting workload measures in future years as flight deck requirements change. This will enable the FAA to evaluate workload measurement plans for crew size substantiation and workload acceptability during aircraft certification efforts. Guidelines will be provided for selecting workload measures that are valid, reliable, and applicable for airplane certification.

The manufacturers of commercial transport aircraft are aware of the special responsibilities and caution needed to assure a safe aircraft design. The technical approach for this contract has emphasized established scientific methodology and practical application of methods in the selection of workload measures for aircraft certification. A step-by-step procedure has been used for identifying candidate workload measures and then confirming the validity, reliability, and applicability of the candidates by means of rigorous aircraft simulation testing. The procedures used have enabled quantitative descriptions to be made of the statistical validity and reliability of the workload measures employed in testing to date.

Results from the part-task simulation testing phase of the contract were presented at a two-day workshop held in Seattle, Washington, on September 15 and 16 at the Crowne Plaza Hotel. Eighty attendees were drawn from a wide cross section of operational personnel and potential workload measurement users. University scientists from the first workshop held in Long Beach, California, on February 24 and 25, 1987 were invited to attend to help assess the scientific quality of the results and the appropriateness of the conclusions drawn from the data and test designs. The remainder of the attendees were from aerospace industry, government regulatory agencies, military workload experts, and NASA.

Attendees were asked to provide comments/discussion regarding their views of the part-task testing results. They were also asked to comment on the validity of the data and what the data suggested regarding the applicability of the candidate workload measures to aircraft certification. Audience comments were reviewed and incorporated prior to the full-mission testing phase of the contract. Included in these proceedings are copies of all the workshop presentations, results of analysis of the data collected in part-task testing and the results of the time-line analysis. In addition, a summary of the discussions held over the two days is included.
**USAF/FAA REVIEW OF WORKLOAD MEASUREMENT METHODS:**
**PART-TASK SIMULATION DATA SUMMARY WORKSHOP**

**ATTENDEE LIST**
**WORKSHOP #2**
September 15 and 16, 1987

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**USAF/FAA REVIEW OF WORKLOAD MEASUREMENT METHODS: PART-TASK SIMULATION DATA SUMMARY WORKSHOP**

**PROGRAM - WORKSHOP #2**  
September 15 and 16, 1987

**DAY 1**

<table>
<thead>
<tr>
<th>TIME</th>
<th>EVENT</th>
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| CARLSBAD ROOM    | **08:30-09:00 am**  
Registration (Continental breakfast available) (Nancy Whitman) |
| **09:00-09:10 am** | Welcome from USAF sponsor  
(Harry Britten-Austin) |
| **09:10-09:30 am** | Welcome/opening remarks from Boeing  
(Brien Wygle- Vice President Flight Operations) |
| **09:30-09:40 am** | Workshop objective  
(George Boucek) |
| **09:40-10:10 am** | Opening remarks from FAA sponsor  
(Pete Hwoschinsky) |
| **10:10-10:40 am** | Program overview: Validity, reliability criteria for the selection of measures  
(Mike Biferno) |
| **10:40-11:00 am** | Break |
| **11:00-11:20 am** | Application of data  
(George Boucek) |
| **11:20-11:50 am** | Description of part-task simulation  
(Diane Sandry-Garza) |
<p>| <strong>11:50-01:00 pm</strong> | Luncheon |</p>
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<tr>
<td>CARLSBAD ROOM</td>
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<td>01:00-01:40 pm</td>
<td>Subjective workload measurement: A review of the data regarding validity, reliability, applicability (Bill Corwin)</td>
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<tr>
<td>01:40-02:20 pm</td>
<td>Physiological workload measurement: A review of the data regarding validity, reliability, applicability (Sam Metalis)</td>
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<td>02:20-02:40 pm</td>
<td>Break</td>
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<tr>
<td>02:40-03:20 pm</td>
<td>Performance workload measurement: A review of the data regarding validity, reliability, applicability (Bill Corwin)</td>
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<td>03:20-04:00 pm</td>
<td>Analytical workload assessment: A description of the TLA task and a review of the data (Aileen Logan)</td>
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<td>04:00-05:00 pm</td>
<td>Question/Answer Session (George Boucek, Mike Biferno)</td>
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<td>05:00 pm</td>
<td>Adjourn</td>
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<td>06:00 pm</td>
<td>Regroup in lobby for bus to Fisherman's Terminal (evening includes a cruise and dinner buffet)</td>
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<tr>
<td>10:00 pm</td>
<td>Return to Crowne Plaza</td>
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# USAF/FAA Review of Workload Measurement Methods: Part-Task Simulation Data Summary Workshop

## Program - Workshop #2

September 15 and 16, 1987

### Day 2

**Time** | **Event**
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CARLSBAD ROOM | **Continental breakfast available**
08:30-09:00 am | Comparisons of workload measures (Panel)
09:00-10:30 am | **Break**
10:30-10:50 am | Description of full mission simulation (Diane Sandry-Garza, Bill Corwin)
10:50-11:20 am | Discussion of full mission simulation (George Boucek, Mike Biferno)
11:20-12:20 am | **Concluding remarks** (George Boucek, Mike Biferno)
12:20-12:30 pm | Luncheon Buffet
12:30 pm | }
WELCOME AND OPENING REMARKS FROM THE USAF
Sq. Ldr. HARRY BRITTEN-AUSTIN
Wright-Patterson Air Force Base

Edited Transcript

Good morning Ladies and Gentlemen, welcome to the second Workshop of this Crew Workload Measurement program. It's nice to see so many of you made it here. We obviously gave you a good time at the first workshop. Many of you worked very hard at that first workshop, and I hope you're going to be pleased with the results you'll see today and tomorrow which are a direct consequence of your efforts in Long Beach in February. In addition to those who attended in February, we have many user groups represented here today because we feel the flavor of the program has now drifted toward implementation of the measurement techniques. I'm pleased to see so many representatives from the FAA, APA, ALPA, ATA, from NASA, the academic community, and even from overseas.

I've just been asked to introduce the key players in the program. First, my co-sponsor from the FAA, Pete Hwochinsky, and the two people who manage the contract, Mike Biferno from Douglas Aircraft and George Boucek from The Boeing Company.

I think you'll find it an interesting couple of days. We have some special diversion planned for you as well. This evening's cruise promises to be very entertaining. We were well looked after at the social last night, and we're hoping you'll have two very pleasant days here. Thank you.
WELCOME AND OPENING REMARKS FROM THE BOEING COMPANY

BRIEN WYGLE

Vice-President Flight Operations
Boeing Commercial Airplane Company

Edited Transcript

I'd like to welcome everyone to Seattle from The Boeing Company. I went to the cocktail party last night and enjoyed it very much. I hope you all have a good stay. Since we've had a very dry summer, and we knew you'd like it wet in Seattle like it's supposed to be, we've even provided rain.

I'm flattered to be asked to address this erudite gathering on the subject of workload. We have been dealing with the subject now for a very long time. We owe thanks to the SAE S-7 committee, for example, and many other organizations and engineering designers for providing us with today's cockpits. Certainly we have come a long way.

I think the reason we have such good attendance and why this is an important session is, in fact, because today you are where the action is. What you're doing now is what's important. We have learned a lot over the years, but the study of workload and human factors and their role in preventing accidents is certainly a wave of the future. That is what we must devote ourselves to, perhaps in a more informed and less hysterical manner, than in the past.

In presenting accident statistics there is always a classic slide which shows that accidents occur most often in approach and landing. I want to point out, however, that we mustn't make too many early assumptions. I will refer to two fairly recent accidents.

First, the 747 accident in Japan, one of the most tragic and terrible accidents of all times, was not due to the crew's failure. There was little the crew could do to save themselves. Certainly one of the most terrifying things to a pilot outside of in-flight fire, is to be left with a hydraulically controlled airplane with no hydraulics to control surfaces. That accident nonetheless was due to human failure. The original problem was an improper repair done to the rear bulkhead which resulted in material failure. It is a long and complex story of a series of minor human errors which led to fatigue failure and a catastrophic accident. To trace and correct those things is very complicated because it's not just human failure and its not just the engineering of the job. We have to see why people fail, why this accident was not prevented.

The second is the more recent MD-80 accident in which it appears, although I don't like to second guess the NTSB, that the flaps were not extended. It has been suggested that there was no warning horn, and I suppose that we've learned to depend on those warning horns to tell us that we're configured for take off. There are only a few things that you have to be certain about during take off.
One is your flaps. Nonetheless, if the horn had been pulled by the circuit breaker, because we've all seen warning horns silenced, we have to ask ourselves why the crew would do that. We must not just talk to the crew and tell them not to pull the circuit breaker. We have to look at "why" they pulled it. Where in our design did we permit that to occur? That's the thing that the designers are asking themselves every day.

I would like to tell you a little about a study done at The Boeing Company recently by two of our engineers, Les Lautman and Peter Gallimore (included in this mailing is a complete copy of this study). They noted that in line with Pareto's thinking and Pareto's charts, 15% of the world's airlines had 80% of the accidents and 80% of the airlines had no accidents. They took a recent 10 year period and looked at Boeing customers only. They thought we should be working on the concentration of where the accidents are. That's a little difficult to do however. It's not the manufacturer's job to tell the airlines how to prevent accidents, and manufacturer's are not too well received when they attempt to do so. Lautman and Gallimore decided to visit the airlines that traditionally don't have accidents to see what those airlines did in flight operations. I'm sure there's room for significant statistical error, but they came up with a representative number of airlines, both domestic and international, that had good safety records. They asked those airlines what they did in flight operations, and listed all these things to see what these airlines did in common. Not surprisingly, the airlines had a great deal in common.

First, they had a well organized and disciplined flight operations department. They had people who were paying full-time attention to the administration of the department. They had a corporate attitude of flight safety, because we know if you're trying to run a flight operations department and you can't get the budget you need from the president and the chief financial officer, you cannot provide the needs for a safe flight operations. In all cases the corporate management was safety conscious. There was sufficient response from the bean counters and other non-flying people that they recognized the needs and provided the means to have a safe flight operation.

Another factor in common was the concept of standardization pilots. That is, there was a pilot assigned to be the standardization pilot. He would see that all the flight crews were using the same procedures. They had a check-airman program where the line pilot was continually checked, in many cases beyond the governmental requirements. They had mandatory briefings before takeoff and before approach. This was a procedure pilots had to go through no matter how routine it seemed. The pilot was required to brief before take off and before approach, including the missed approach. It is this discipline, we believe, that contributes to their safety.

Another common factor among these airlines was that they all owned their own simulators. They did very little contract training. If they had a small fleet of a certain type of aircraft that didn't justify a simulator, they might contract with someone else, but they would send their own instructors and would use their own procedures. They developed standardized approaches with the same procedures for callouts, the same requirements for a stabilized approach - on
speed, on glide slope and so on. Each of these companies tightly controlled the cockpit procedures and the cockpit language. There was no room for casual language usage. The crew had to call everything by its right name. The training was extensive, in many cases more than the requirements. Most often these airlines used the LOFT concept of line oriented flight training.

It has been my experience that most of the things I’ve mentioned tend to be missing or improperly applied in those airlines that have a bad safety record. I’m sure my friend Mr. Knickerbocker from Douglas Aircraft would agree from his observation of customer operations. We know, in fact, how to create a safe airline. It is not always done however, for many reasons.

I believe the modern cockpit to be a very good one. I think starting with the 757/767 and A310, to be followed by the MD-80 advanced and 737 advanced cockpits and followed by the A320, MD11 and 747-400, these cockpits are really very much the same idea. There are detail differences but everyone has a similar concept of what a modern cockpit is. I think we would all agree that the three man cockpit is an out of date and unsatisfactory cockpit in the world today. That was certainly controversial, but once put to bed that idea has swept widely across the industry. In fact two men make an ideal human relation combination to operate an airplane.

There is criticism of the cockpits today, that we have provided an environment where the pilot may become overly complacent and not be sufficiently motivated to do the job properly, resulting in errors. There may very well be justification for this. However, there are other times when the pilot sees no evidence of insufficient workload. For instance, when the pilot gets an approach change at the last minute and is making inputs into his flight management computer, I think those are times when he is quite heavily loaded. Certainly, if we can simplify the number of keystrokes required to input an approach change, that would be a valuable improvement. Of course, people are working on that. We certainly have to address the subject of workload; where it is high and where it isn’t sufficiently high. The idea of keeping people alert is an important one.

The concept of fatigue is also important. None of us work very well when we’re on the verge of falling asleep. The fatigue problem is a very difficult one to approach. No matter how complicated we make our duty time allowables, we’re never going to really know the state of that pilot when he gets into the airplane. We assume if a pilot leaves at 9 o’clock in the morning and is bright and rested and in good shape, he can fly a long time. I suppose that’s generally true, but we know that sometimes people have a bad night, or sometimes they have mental stress. We also know that some pilots who take off at 6 o’clock in the evening are very fresh because they’re those lucky people who can lay down and sleep 4 hours in the afternoon. Not all of us can do that. So we really don’t know the state of the pilot when he gets into the cockpit. We really don’t know what an individual’s mental and physical state will permit him to do on that particular day. I certainly don’t know how to measure that, but perhaps it’s food for thought.

Finally, I would like to comment on the commitment of The Boeing Company to this particular group and to the subject of workload and human factors in general. We have combined our pilots, engineers and human factors people into a group
that is jointly responsible for the development of flight decks. We are committed to flight deck improvement from both a working environment and a safety point of view. I think we have made that commitment, and it is clear to me that our colleagues at Douglas and Aerospatiale have made similar commitments. There's no doubt that the industry today is working hand in glove with the government, with airlines, with others, to provide the kind of cockpit we feel is correct.

I am very impressed to see both the number and the qualifications of the people who have attended this workshop. I would like to complement Joe Tymczysyn, Diane Sandry-Garza, and Aileen Logan and the staff who have prepared for this workshop, and I hope and trust that you will have both a pleasant and useful stay. Thank you.
Objectives
- Describe the technical approach to the part-task simulation
- Review results of part-task simulation
- Gather input on the results
- Describe the technical approach to the full-mission simulation
- Gather input on the simulation approach
Good morning ladies and gentlemen, I would like to reaffirm the welcome from our contractors, and thank all of you for taking your valuable time to attend this workshop and assist us in providing support to you in minimum flightcrew determination.

Let me take a few moments to inform you how this project is organized, who is involved, and how what we do will be used. First of all, regional requirements are recognized by the office of Aviation Standards in Washington. They are prioritized and then given to the appropriate R&D office for action.

The Cockpit Technology Program Office (for whom I work) was asked to develop this project in response to Aviation Standards and to the President's Commission on Crew Complement. Several (14) of the recommendations therein referred to developing and implementing improved methods of measuring aircrew workload. Simultaneously, the FAA Northwest Mountain Region developed a draft advisory circular on minimum flight crew requirements (AC 25.1523), which has been circulated for comment. In order to provide guidance materials for evaluating compliance with this circular, we developed a project to document existing methods of workload measurement, to organize and catalogue promising new techniques, and to test a representative sample of each type of physiological, subjective, and performance related measures. We did this through a seed money contract from our Interagency Agreement with the Air Force to take advantage of existing expertise and manufacturers' experience. The Douglas and Boeing Companies have agreed to share part of the burden of this effort through in house support.

At the first workload workshop which we held last February, we asked an assemblage of experts (many of whom are here today) to review a rather lengthy list of workload measures and recommend to us which ones we should consider for testing and inclusion in the Advisory Circular. At the conclusion of the part task and full mission simulations and our evaluation thereof, we will provide a report to the Northwest Mountain Region Aircraft Certification Directorate and Aircraft Evaluation Groups; and FAA Headquarters Flight Standards with our recommendations.

Most of you here today already have a good working knowledge of what workload measurement is, and how it is used in design. However, on the certification side, we have engineers and certification specialists who are expert pilots who use that expertise to evaluate, by comparison, the proposed new systems and cockpit suites during all phases of design, development and production. Our intention in the project is to provide additional means for those specialists to gain an understanding of the workload demands of any new design. We have no intention of replacing the existing well proven and highly successful means of subjective assessment. We see this effort as an adjunct to the existing system when the advisory circular is published in final form. The certification process will continue as before with the addition of looking at manufacturers' documentation of acceptable means of objective workload assessment as
outlined in the AC. Once we have made our report to Flight Standards, our portion of the project will be complete.

However, we feel strongly that our findings should be validated through flight test verification. Some follow on R&D should be performed to evaluate advanced techniques, and to provide a method or means of including new techniques into the AC as appropriate.

Finally, the results which we will have gathered for FAR part 25 aircraft should be adapted for use with FAR part 23 certification use, since it is generally conceded that single pilot IFR flight in a small plane can be one of the most demanding taskloads.

I will let Douglas and Boeing contractors fill you in on the details of our project. George Boucek has given you our objectives. Now Mike Biferno will give you a program overview.

Thank you.
PROGRAM OVERVIEW

VALIDITY AND RELIABILITY CONSIDERATIONS

ASSESSMENT OF CREW WORKLOAD MEASUREMENT
METHODS, TECHNIQUES, AND PROCEDURES
PROGRAM OBJECTIVE

PROVIDE GUIDELINES FOR SELECTING WORKLOAD MEASURES WHICH ARE VALID, RELIABLE, AND APPLICABLE FOR AIRCRAFT CERTIFICATION.

- FLEXIBLE BASIS FOR SELECTING MEASURES
- ENABLE FAA TO EVALUATE WORKLOAD MEASUREMENT PLANS
PROGRAM SCOPE

IDENTIFY EXISTING CANDIDATE WORKLOAD MEASURES

SELECT THE MOST VALID, RELIABLE, AND APPLICABLE MEASURES FOR TESTING
  - INITIAL SCREENING WITH LITERATURE REVIEW AND WORKSHOP #1
  - FINAL SCREENING IN PART-TASK SIMULATION
  - SUITABLE FOR FULL-MISSION SIMULATION OR IN-FLIGHT

EVALUATE COMMERCIAL TRANSPORT ENVIRONMENT

DEVELOP LIST OF ACCEPTABLE WORKLOAD MEASURES

DEMONSTRATE THE PROCESS OF WORKLOAD MEASURE SELECTION
APPROACH

IDENTIFY CANDIDATE MEASURES

DETERMINE BEST MEASURES

PROVIDE GUIDELINES FOR MEASURE SELECTION
IDENTIFY CANDIDATE MEASURES

IDENTIFY SELECTION CRITERIA

CONDUCT LITERATURE REVIEW

DEVELOP FACT MATRICES

CONDUCT FIRST WORKSHOP

DETERMINE LIST OF MEASURES FOR TESTING
## LIST OF MEASURES FOR TESTING
### IN PART-TASK SIMULATION

<table>
<thead>
<tr>
<th>Subjective</th>
<th>Performance</th>
<th>Physiological</th>
</tr>
</thead>
<tbody>
<tr>
<td>TLX</td>
<td>Control Activity</td>
<td>Heart</td>
</tr>
<tr>
<td>SWAT</td>
<td>Wheel Column Pedal</td>
<td>Rate Rate Variability</td>
</tr>
<tr>
<td>1-20 Overall</td>
<td>Secondary Task</td>
<td>HR Spectral Analysis</td>
</tr>
<tr>
<td></td>
<td>Response Time Error</td>
<td>Blood Pressure Respiration</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Eyeblink</td>
</tr>
</tbody>
</table>
DETERMINE BEST MEASURES

PERFORM PART-TASK SIMULATION TESTING

CONDUCT SECOND WORKSHOP

PERFORM FULL-MISSION SIMULATION TESTING

DEVELOP LIST OF ACCEPTABLE WORKLOAD MEASURES
PERFORM PART-TASK SIMULATION TESTING

VALIDITY: ARE YOU MEASURING WHAT YOU THINK YOU ARE MEASURING?

 ARE RELEVANT TYPES OF WORKLOAD EXAMINED? (CONTENT)

 DOES MEASURE CHANGE WHEN WORKLOAD IS VARIED? (CONSTRUCT)

 DOES MEASURE AGREE WITH TIME-LINE ANALYSIS? (CRITERION-RELATED)

 RELIABILITY: HOW STABLE IS THE MEASURE?

 DOES MEASURE YIELD SAME RESULT WITH SAME PILOT? (TEST-RETEST)

 DOES MEASURE YIELD SAME RESULT WITH DIFFERENT PILOTS? (INTER-RATER)
### Test-Retest Reliability

**High Reliability**

<table>
<thead>
<tr>
<th>Athlete</th>
<th>Test</th>
<th>Retest</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>10.5</td>
</tr>
<tr>
<td>2</td>
<td>9.5</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>10.5</td>
<td>11</td>
</tr>
<tr>
<td>4</td>
<td>11.5</td>
<td>11.5</td>
</tr>
<tr>
<td>5</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>6</td>
<td>12.5</td>
<td>12</td>
</tr>
</tbody>
</table>

**Low Reliability**

<table>
<thead>
<tr>
<th>Athlete</th>
<th>Test</th>
<th>Retest</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11</td>
<td>10.5</td>
</tr>
<tr>
<td>2</td>
<td>10.5</td>
<td>9.5</td>
</tr>
<tr>
<td>3</td>
<td>11</td>
<td>12.5</td>
</tr>
<tr>
<td>4</td>
<td>11.5</td>
<td>10</td>
</tr>
<tr>
<td>5</td>
<td>12</td>
<td>12.5</td>
</tr>
<tr>
<td>6</td>
<td>11.5</td>
<td>11.5</td>
</tr>
</tbody>
</table>

Correlation: $r = 0.2$ for Low Reliability, $r = 1.0$ for High Reliability

*Example: 100-meter dash in seconds*
INTER-RATER RELIABILITY
(Example: Platform Dive)

<table>
<thead>
<tr>
<th>Low Reliability</th>
<th>Judge</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>8.2</td>
<td>9.7</td>
<td>8.4</td>
<td>8.1</td>
<td>6.0</td>
</tr>
</tbody>
</table>

| High Reliability |
|-------------------|-------|---|---|---|---|---|
| Judge             | 1     | 2 | 3 | 4 | 5 |
|                   | 8.2   | 8.3 | 8.4 | 8.1 | 8.4 |
Application of Data
Practicality

- Costs incurred
- Time constraints
- Equipment constraints
Costs Incurred

- Equipment costs
- Installation and preparation costs
- Time and schedule impact
- Flight and simulation costs
- Documentation costs
Time Constraints

- Certification program schedule
- Production schedules
- Delivery schedules
Equipment Constraints

- Limited hardware space
- Limited panel space
- Large distance between pilot and data collection hardware
- Potential signal interference
- Inability to change flight deck configuration
Applicability

- Environmental considerations
- Pilot acceptance
- Certification considerations
Environmental Considerations

- Must be capable of gathering data under the constraints of the flight environment
  - Part-task simulation
  - Full mission simulation
  - Flight test

- Will be applied to multidimensional task demands that could include unpredictable variations
Pilot Acceptance

- Nonintrusive to flight task
- Compatible with flight safety
- Compatible with normal methods of operation
- Responsive to crew self-image
- Noncareer threatening
Certification Considerations

- Minimal interference with other certification flight test activities
- Technique should be appropriate for the specific phase and objectives of the certification program
- Initial efforts concentrate on those aspects that have changed from the reference aircraft
Workload Factors
FAR-25

1. Controls
2. Displays
3. Procedures
4. Mental and physical effort
5. Monitoring
6. Crew member out of area
7. Automation breakdown
8. Communication and navigation
9. Nonnormals
10. Incapacitated crew member
Crew Workload Assessment

- Analysis
- Simulation
- Flight Test
- Objective of the program to identify assessment or measurement techniques that reliably discriminate changes in workload

- Data from testing used to evaluate discrimination rather than to obtain absolute values of workload

- No intention to look for "red line" values for either overload or underload
Description of
Part-Task Simulation Testing

Diane L. Sandry-Garza
Boeing Commercial Airplane Company
Seattle, Washington
Simulation Facility

- NASA - Ames (MVSRF)
- Boeing 727 motion-base simulator
- High level of fidelity
- ATC simulation
Subjects

- FAR qualified and current 727 airline pilots
- Captain (data collection)
- Confederates
- Representative of population
Simulation Scenarios
## Two Workload Levels

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Weather</th>
<th>Wind</th>
<th>Autopilot</th>
<th>Turbulence</th>
<th>Nonnormals</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Ceiling, 500 ft; visibility, 1 mi</td>
<td>12 kn at takeoff and landing</td>
<td>Inoperative</td>
<td>Significant</td>
<td>Number three engine stall, Hydraulic System B failure, Distractors (i.e., autopressure failure, window overheat)</td>
</tr>
<tr>
<td>Low</td>
<td>Clear</td>
<td>5 kn at takeoff and landing</td>
<td>Operating</td>
<td>Minimal</td>
<td>None</td>
</tr>
</tbody>
</table>
Phases of Flight and Data Collection

- **Ground Speed > 5**
- **Flaps Up** 10,000 ft
- **Passes Thrust Levers Back to Idle**
- **Localizer Alive**
- **Pulls Middle Marker**

**Phase of flight, minutes**
- **Takeoff** 2.7
- **Climb** 3.25
- **Cruise** 7.5
- **Descent** 7.5
- **Approach** 4.7
- **Landing** 1.5

**Data collection windows, minutes**
- **Flaps** 5
- **Passes 5,500 ft**
- **Passes Outer Marker**
# Part-Task Simulation

## Data Collection Windows

<table>
<thead>
<tr>
<th>Flight Phase</th>
<th>Open Measurement Window</th>
<th>Close Measurement Window</th>
</tr>
</thead>
<tbody>
<tr>
<td>Takeoff</td>
<td>Ground speed &gt; 5</td>
<td>Flaps 5</td>
</tr>
<tr>
<td>Climb</td>
<td>Flaps up</td>
<td>1 min later</td>
</tr>
<tr>
<td>Cruise 1</td>
<td>10,000 ft</td>
<td>2 min later</td>
</tr>
<tr>
<td>Cruise 2</td>
<td>3 min after 10,000 ft</td>
<td>2 1/2 min later</td>
</tr>
<tr>
<td>Descent</td>
<td>Throttles to idle</td>
<td>5,500 ft</td>
</tr>
<tr>
<td>Approach</td>
<td>Localizer activation</td>
<td>Outer marker</td>
</tr>
<tr>
<td>Touchdown</td>
<td>Middle marker</td>
<td>1 1/2 min later</td>
</tr>
</tbody>
</table>
Operationally Relevant Types of Workload
FAR 25.1523, Appendix D

- FAA addresses
  - 6 workload functions
  - 10 workload factors

- Map FAR-25 function and factor descriptions into scenarios

- Divide scenarios into high and low workload levels based on objective task demands
Basic Workload Functions
FAR-25

1. Flightpath control
2. Collision avoidance
3. Navigation
4. Communications
5. Operations and monitoring of aircraft engines and systems
6. Command decisions
Workload Factors
FAR-25

1. Controls
2. Displays
3. Procedures
4. Mental and physical effort
5. Monitoring
8. Communication and navigation

9. Nonnormals
6. Crew member out of area
7. Automation breakdown
10. Incapacitated crew member
## Function and Factor Mapping
### Example

<table>
<thead>
<tr>
<th>Time</th>
<th>Function</th>
<th>Factor</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>00:02:15</td>
<td>4,5,6</td>
<td>3,8A</td>
<td>Gear Retract - Start Initial Climb</td>
</tr>
<tr>
<td>00:02:15</td>
<td>4</td>
<td>8A</td>
<td>• Calls, &quot;gear up&quot;</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>5</td>
<td>• Hears F/O, &quot;gear up&quot;</td>
</tr>
<tr>
<td>00:02:15</td>
<td>1,5</td>
<td>2,3,5</td>
<td>• Sees F/O compliance (peripheral vision)</td>
</tr>
<tr>
<td>00:02:15</td>
<td>1,5,6</td>
<td>1,2,3</td>
<td>• Looks to see if airspeed stabilized at approximately V2 + 10</td>
</tr>
<tr>
<td>00:02:35</td>
<td>1,5,6</td>
<td>1,2,3</td>
<td>• Adjusts pitch attitude to maintain V2 + 10 if necessary</td>
</tr>
<tr>
<td>00:02:35</td>
<td></td>
<td></td>
<td>• Sets FD pitch knob to proper pitch attitude</td>
</tr>
<tr>
<td>00:02:35</td>
<td></td>
<td></td>
<td>Cleared Direct Sacramento Vortac</td>
</tr>
</tbody>
</table>
### Part-Task Simulation

**Function and Factor Tally Sheet**

<table>
<thead>
<tr>
<th>Function</th>
<th>Window</th>
<th>Cruise 2</th>
<th>Non-Normals</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Flightpath</td>
<td>1</td>
<td>0</td>
<td>13</td>
</tr>
<tr>
<td>2. Collision avoidance</td>
<td>2</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>3. Navigation</td>
<td>15</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>4. Communication</td>
<td>2</td>
<td>13</td>
<td>0</td>
</tr>
<tr>
<td>5. Operations and monitoring</td>
<td>11</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td>6. Command decisions</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Physical</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mental</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
</tr>
</tbody>
</table>

**Flight Segment** SFO→SCK

- 0
- 0
- 1
- 0
- 1
- 0
### Physical/Mental Task Loadings

<table>
<thead>
<tr>
<th>Measurement Window</th>
<th>Flight Segment</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>SFO-SCK</td>
<td>SMF-SFO</td>
</tr>
<tr>
<td>Takeoff</td>
<td></td>
<td>75 / 124</td>
<td>71 / 117</td>
</tr>
<tr>
<td>Climb</td>
<td></td>
<td>39 / 75</td>
<td>38 / 78</td>
</tr>
<tr>
<td>Cruise 1</td>
<td></td>
<td>13 / 46</td>
<td>10 / 37</td>
</tr>
<tr>
<td>Cruise 2</td>
<td></td>
<td>1 / 6</td>
<td>1 / 5</td>
</tr>
<tr>
<td>Descent</td>
<td></td>
<td>47 / 137</td>
<td>45 / 141</td>
</tr>
<tr>
<td>Approach</td>
<td></td>
<td>63 / 185</td>
<td>66 / 199</td>
</tr>
<tr>
<td>Land</td>
<td></td>
<td>28 / 62</td>
<td>28 / 62</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td></td>
<td><strong>266 / 635</strong></td>
<td><strong>259 / 637</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>901</strong></td>
<td><strong>896</strong></td>
</tr>
</tbody>
</table>
Dependent Measures

- Subjective
- Physiological
- Performance
- Task timeline analysis
Dependent Measures

- Subjective
  - NASA TLX
  - SWAT

- Physiological
  - Heart rate variability
  - Eye blinks
  - Eye movement

- Performance
  - Primary task
  - Secondary task

- Analytical
  - Task timeline analysis
Subjective Measures

- Subjective workload assessment technique (SWAT)
- Task load index (TLX)
- Overall workload score (simple 20-point scale)
Subjective Measures

- Inflight (direct measurement)
- Postflight (videotape)
- Example measures
- NASA TLX
- SWAT
# Part-Task Simulation

Subjective Measures

<table>
<thead>
<tr>
<th>In-Simulator (Four Phases)</th>
<th>Post-Flight Videotape (Seven Phases)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Takeoff-Cruise</td>
<td>• Takeoff</td>
</tr>
<tr>
<td>• Cruise</td>
<td>• Climb</td>
</tr>
<tr>
<td>• Descent-landing</td>
<td>• Cruise 1</td>
</tr>
<tr>
<td>• Overall</td>
<td>• Cruise 2</td>
</tr>
<tr>
<td></td>
<td>• Descent</td>
</tr>
<tr>
<td></td>
<td>• Approach</td>
</tr>
<tr>
<td></td>
<td>• Landing</td>
</tr>
</tbody>
</table>
Physiological Measures

- Eyeblink rate
- Eye movement
- Heart
  - Rate
  - Rate variability
- Heart spectral analysis
  - Blood pressure component
  - Respiration component
Performance Measures

- Primary Task
  - Reversals
    - Stick
    - Aileron
  - Rudder
  - Throttle

- Approach and landing
  - Flightpath error
  - Glideslope and localizer variability
  - Altitude at outer, middle, and inner markers

- Secondary Task
  - Sternberg RT task
Secondary Task

- Two “flight numbers” are designated positive probes
  - Pilot’s own flight number (United 247)
  - Another aircraft flight number (United 241)
- Pilot is instructed to respond as quickly and accurately as possible
- Pilot response is to toggle “push to talk” switch
Part-Task Simulation

Secondary Task

Captain's Memory Set:
- Airplane call sign
- Other aircraft

Designated Airline: United
Secondary Task Measures

- Response time
- Probe accuracy
Timeline Analysis (TLA)

Computes the ratio of time required to time available throughout the flight mission scenario.
Timeline Analysis

- Evaluates for each crew member:
  - Hand activity time
  - Eye activity time
  - Cognition time

- Estimates the times a crew member is occupied by:
  - Visual task
  - Motor task
  - Cognitive task
  - Verbal task
  - Auditory task
Task Timeline Analysis (TLA)

- Selected segments
- Proven TLA method
- Identifies high and low task-demand levels
- Validity of workload measures against proven tool
Part-Task Simulation Protocol

- Greet pilot
- Provide tape-recorded instructions and answer questions
- Provide differences training
- Subjective training
  * * Lunch * *
- Instrument pilot for physiological measures
- In-cab differences training
- Experimental runs
- Post-flight subjective measures
- Debriefing
Part-Task Simulation
Experimental Variables

Four factors: 2 x 2 x 4 x 7 design
Factor one: workload (two levels) low and high
Factor two: route (two levels) SFO - SCK and SMF - SFO
Factor three: four possible orders A, B, C, and D
Factor four: measurement epoch (task loadings) (seven levels)
   1. Takeoff
   2. Climb
   3. Cruise 1
   4. Cruise 2
   5. Descent
   6. Approach
   7. Landing
# Part-Task Simulation

## Experimental Design

### Session One:

<table>
<thead>
<tr>
<th>Order Number</th>
<th>SWAT Inflight</th>
<th>NASA/TLX Post-Flight</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>SFO - SCK (LO)</td>
<td>SMF - SFO (HI)</td>
<td>SMF - SFO (LO)</td>
</tr>
<tr>
<td>SMF - SFO (HI)</td>
<td>SFO - SCK (LO)</td>
<td>SFO - SCK (HI)</td>
</tr>
</tbody>
</table>

|            |                |                      |
| Ss 1,9,17  | Ss 2,10,18     | Ss 3,11              |

### Session Two:

|            |                |                      |
| SMF - SFO (HI) | SFO - SCK (LO) | SMF - SFO (LO)       |
| SFO - SCK (LO) | SMF - SFO (HI) | SFO - SCK (HI)       |

|            |                |                      |
| Ss 5,13    | Ss 6,14        | Ss 7,15,19           |

### Session One:

<table>
<thead>
<tr>
<th>NASA/TLX Inflight</th>
<th>SWAT Post-Flight</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>SFO - SCK (LO)</td>
<td>SMF - SFO (HI)</td>
</tr>
<tr>
<td>SMF - SFO (HI)</td>
<td>SFO - SCK (LO)</td>
</tr>
</tbody>
</table>

|            |                |                      |
| Ss 5,13    | Ss 6,14        | Ss 7,15,19           |

### Session Two:

|            |                |                      |
| SMF - SFO (HI) | SFO - SCK (LO) | SMF - SFO (LO)       |
| SFO - SCK (LO) | SMF - SFO (HI) | SFO - SCK (HI)       |

|            |                |                      |
| Ss 8,16,20 |                |                      |
SUBJECTIVE MEASURES

All simulation sessions were video taped. Subjects viewed the video tapes of their flights at the end of a day’s session for the purpose of subjective rating. Half of the subjects used the Subjective Workload Assessment Technique (SWAT) and the other half used the NASA Task Load Index (TLX).

Both measures, SWAT and TLX, could discriminate the predicted difference in workload. Both measures showed high INTER-RATER reliability as well. The measures were highly correlated, $r = .97$, indicating that the measures are tapping the same underlying phenomena.

On the transparencies dots are used to denote a statistically significant relationship.

- On the chart including "means" for the workload measure the dot represents a significant difference between low and high workload for a given measurement window.

- On the chart including "correlation coefficients" for the workload measure the dot represents a significant correlation comparing test to retest for a given measurement window.

Following are the transparencies presented on the analysis of the subjective measures data.
SUBJECTIVE MEASURES

- SUBJECTIVE WORKLOAD ASSESSMENT TECHNIQUE (SWAT)
- TASK LOAD INDEX (TLX)
- OVERALL WORKLOAD SCORE (SIMPLE 20-POINT SCALE)
SUBJECTIVE WORKLOAD

ASSESSMENT TECHNIQUE (SWAT)

- 3 BIPOLAR SCALES (TIME, MENTAL EFFORT, STRESS)
- 3 POSSIBLE RATING VALUES FOR EACH RATING SCALE
- USES CONJOINT MEASUREMENT THEORY
- YIELDS SINGLE WORKLOAD SCORE WITH VALUE BETWEEN 0 – 100
SWAT WORKLOAD SCORES
(Redone with correct solution)

LEGEND

[Shaded] LOW WORKLOAD
[Solid] HIGH WORKLOAD

SWAT SCORES

WINDOWS

W1 13.2 18.4
W2 17.5 24.6
W3 12.5 49.8
W4 7.8 4
W5 14.7 29.7
W6 18.5 35
W7 18.5 33.7
TASK LOAD INDEX (TLX)

- 6 BIPOLAR SCALES (MENTAL DEMAND, PHYSICAL DEMAND, TEMPORAL DEMAND, PERFORMANCE, EFFORT, FRUSTRATION)
- 20 POSSIBLE RATING VALUES FOR EACH BIPOLAR SCALE
- USES CONJOINT MEASUREMENT THEORY
- YIELDS SINGLE WORKLOAD SCORE WITH VALUE BETWEEN 0 – 100
TEST-RETEST RELIABILITY SCORES
TLX REDONE WITH CORRECT WEIGHTING

LEGEND

- LOW WORKLOAD
- HIGH WORKLOAD

<table>
<thead>
<tr>
<th>WINDOWS</th>
<th>W1</th>
<th>W2</th>
<th>W3</th>
<th>W4</th>
<th>W5</th>
<th>W6</th>
<th>W7</th>
</tr>
</thead>
<tbody>
<tr>
<td>RELIABILITY SCORES</td>
<td>.79</td>
<td>.61</td>
<td>.57</td>
<td>.56</td>
<td>.83</td>
<td>.87</td>
<td>.96</td>
</tr>
</tbody>
</table>
OVERALL WORKLOAD SCORE

- ONE BIPOLAR SCALE (OVERALL WORKLOAD)
- 20 POSSIBLE RATING VALUES FOR SCALE
**MEAN SCORES**

SIMPLE WORKLOAD RATING
LO–HI TWENTY POINT SCALE

<table>
<thead>
<tr>
<th>WINDOW</th>
<th>LOW WORKLOAD</th>
<th>HIGH WORKLOAD</th>
</tr>
</thead>
<tbody>
<tr>
<td>W1</td>
<td>3.2</td>
<td>3.9</td>
</tr>
<tr>
<td>W2</td>
<td>3.6</td>
<td>4.8</td>
</tr>
<tr>
<td>W3</td>
<td>3.4</td>
<td>8.5</td>
</tr>
<tr>
<td>W4</td>
<td>2.2</td>
<td>7.8</td>
</tr>
<tr>
<td>W5</td>
<td>3.8</td>
<td>6.1</td>
</tr>
<tr>
<td>W6</td>
<td>3.4</td>
<td>6</td>
</tr>
<tr>
<td>W7</td>
<td>4.7</td>
<td>5.5</td>
</tr>
</tbody>
</table>

**LEGEND**

- LOW WORKLOAD
- HIGH WORKLOAD

**PHASE OF FLIGHT**

DISCRIMINATION

LOW WORKLOAD Ø / 21
HIGH WORKLOAD 5 / 21
TEST–RETEST RELIABILITY
SIMPLE WORKLOAD RATING
LO–HI TWENTY POINT SCALE

(DF ≥ 7)

LEGEND
LOW WORKLOAD
HIGH WORKLOAD

CORRELATION COEFFICIENT

W1  W2  W3  W4  W5  W6  W7

0.8  0.37  0.66  0.45  0.51  0.48  0.78
## Subjective Measures Summary

<table>
<thead>
<tr>
<th></th>
<th>SWAT (Group)</th>
<th>TLX</th>
<th>OWS</th>
</tr>
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<tbody>
<tr>
<td><strong>Validity</strong></td>
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<td></td>
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<tr>
<td><strong>Workload Discrimination</strong></td>
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<tr>
<td>Differences between low and high workload flights?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Low-high differences? (7 possible)</td>
<td>2</td>
<td>3</td>
<td>3</td>
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<tr>
<td><strong>Phase of Flight Discrimination</strong></td>
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<tr>
<td>Differences between phase of flight? (Low)</td>
<td>No</td>
<td>No</td>
<td>No</td>
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<tr>
<td>Phase of flight differences?</td>
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<tr>
<td>Differences between phase of flight? (High)</td>
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<td>Yes</td>
<td>Yes</td>
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<tr>
<td>Phase of flight differences?</td>
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<td>5</td>
</tr>
<tr>
<td><strong>Reliability</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Test-retest correlations day 1 to day 2 (14 possible)</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Inter-rater agreement each pilot correlated to group average</td>
<td>78%</td>
<td>78%</td>
<td>78%</td>
</tr>
</tbody>
</table>
PHYSIOLOGICAL MEASURES

Data was collected for horizontal and vertical eye movement (including blink), heart rate, and heart rate variability. Pilots were instrumented with Beckman mini-cup electrodes to record vertical and horizontal eye movement and had Electrocardiogram electrodes applied to the chest to record heart rate.

Although the data demonstrates good reliability for both TEST-RETEST and INTER-RATER, eyeblinks per minute cannot discriminate low and high workload conditions.

Inter-beat intervals (IBI’s), which tell how much time occurs between heart beats, rather than heart rate, which refers to how many beats occur in a minute, was used in the data analysis. The MEAN and STANDARD DEVIATION of the IBI values for each window were computed. The MEAN IBI measure was sensitive to the differences between low and high workload conditions. In addition it could discriminate phases of flight (between the measurement windows in a given workload condition) better than any other workload measure in the present study. The reliability measures, both TEST-RETEST and INTER-RATER, were consistently high for the mean IBI measure of workload. IBI VARIABILITY was not able to discriminate the difference between low and high workload conditions, although a strong trend exists. TEST-RETEST reliability for IBI VARIABILITY was not as high as IBI MEAN, nor was INTER-RATER reliability as high as the IBI MEAN data.

A heart rate spectral analysis was also conducted using software provided by Randall Harris and Allen Pope of NASA-Langley. The Blood Pressure Component, predicted to decrease when the pilot is engaged in a cognitive task, was not able to discriminate the difference between low and high workload. It was also poor in reliability and it had the worst performance on TEST-RETEST and INTER-RATER reliability measures of all the physiological workload measures. The Respiration Component was able to discriminate the low and high workload conditions. Similar to the other heart spectral analysis measure, the Respiration Component did not demonstrate high reliability in either the TEST-RETEST or INTER-RATER reliability measures.

On the transparencies dots are used to denote a statistically significant relationship.

- On the chart including "means" for the workload measure the dot represents a significant difference between low and high workload for a given measurement window.
- On the chart including "correlation coefficients" for the workload measure the dot represents a significant correlation comparing test to retest for a given measurement window

Following are the transparencies presented on the analysis of the physiological data.
PHYSIOLOGICAL MEASURES

- EYEBLINK RATE

- HEART
  - RATE
  - RATE VARIABILITY

- HEART SPECTRAL ANALYSIS
  - BLOOD PRESSURE COMPONENT
  - RESPIRATION COMPONENT
EYEBLINK RATE

- BLINKS PER MINUTE = BLINK COUNT/WINDOW TIME
- INCREASES WITH GAZE SHIFTS
  - ATTENDING TO MULTIPLE VISUAL TARGETS
- DECREASES WITH INCREASED CONCENTRATION
  - ATTENDING TO A SINGLE VISUAL TARGET
TEST-RETEST RELIABILITY
EYEBLINK RATE
(DF ≥ <15)

LEGEND
- LOW WORKLOAD
- HIGH WORKLOAD

INTER-RATER
RELIABILITY
56% OF SUBJECTS
AGREE WITH MEAN
HEART RATE (AVERAGED INTER–BEAT INTERVALS)

- HEART RATE (BEATS PER MIN.) = \( \frac{1}{\text{IBI TIME}} \times 60 \)

- VARIES AS A DIRECT FUNCTION OF METABOLIC DEMANDS

- INCREASES WITH INCREASING TASK DEMANDS
MEAN SCORES
HEART BEAT (IBI UNITS):
RATE

LEGEND
- LOW WORKLOAD
- HIGH WORKLOAD

PHASE OF FLIGHT
DISCRIMINATION
LOW WORKLOAD 14 / 21
HIGH WORKLOAD 9 / 21
TEST–RETEST RELIABILITY
HEART BEAT (IBI UNITS): RATE
(DF ≥ 15)

LEGEND
- LOW WORKLOAD
- HIGH WORKLOAD

INTER-RATER RELIABILITY
78% OF SUBJECTS AGREE WITH MEAN
HEART RATE VARIABILITY

- HEART RATE VARIABILITY = STANDARD DEVIATION OF IBI DATA
- REFLECTS THE SUM OF ALL SOURCES EFFECTING CHANGES IN HEART RATE
Schmitt trigger level

IBI

Power, msec²

Heart rate variability proportional to area under curve

Frequency, Hz
MEAN SCORES
HEART BEAT (IBI UNITS): VARIABILITY

LEGEND
- LOW WORKLOAD
- HIGH WORKLOAD

PHASE OF FLIGHT
DISCRIMINATION

LOW WORKLOAD ∅ / 21
HIGH WORKLOAD ∅ / 21
TEST-RETEST RELIABILITY
HEART BEAT (IBI UNITS): VARIABILITY
(DF ≥ 15)

LEGEND
- LOW WORKLOAD
- HIGH WORKLOAD

INTER-RATER RELIABILITY
44% OF SUBJECTS AGREE WITH MEAN
HEART SPECTRAL ANALYSIS

- FOURIER TRANSFORM OF IBI DATA
  - YIELDS POWER WITHIN FREQUENCY BANDS

- BLOOD PRESSURE COMPONENT
  - .05 TO .15 hertz
  - DECREASES WHEN ENGAGED IN COGNITIVE TASKS

- RESPIRATION COMPONENT
  - .20 TO .40 hertz
  - INCREASES WITH CHANGES IN METABOLIC DEMANDS
MEAN SCORES
HEART BEAT SPECTRA:
BLOOD PRESSURE COMPONENT

LEGEND
LOW WORKLOAD
HIGH WORKLOAD

PHASE OF FLIGHT
DISCRIMINATION
LOW WORKLOAD 7 / 21
HIGH WORKLOAD 1 / 21
TEST-RETEST RELIABILITY
HEART BEAT SPECTRA:
BLOOD PRESSURE COMPONENT
(DF ≥ 15)

INTER-RATER
RELIABILITY
17% OF SUBJECTS
AGREE WITH MEAN

LEGEND
- LOW WORKLOAD
- HIGH WORKLOAD

CORRELATION COEFFICIENT

WINDOWS

W1 W2 W3 W4 W5 W6 W7
**MEAN SCORES**

HEART BEAT SPECTRA:
RESPIRATION COMPONENT

![Bar Chart]

**LEGEND**
- LOW WORKLOAD
- HIGH WORKLOAD

**PHASE OF FLIGHT**

DISCRIMINATION

LOW WORKLOAD Ø / 21
HIGH WORKLOAD Ø / 21
TEST-RETEST RELIABILITY
HEART BEAT SPECTRA:
RESPIRATION COMPONENT

LEGEND
LOW WORKLOAD
HIGH WORKLOAD

INTER-RATER
RELIABILITY
28% OF SUBJECTS
AGREE WITH MEAN

CORRELATION COEFFICIENT

W1
W2
W3
W4
W5
W6
W7

0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

(0F ≥ 1.5)
# PHYSIOLOGICAL MEASURES

## SUMMARY

### VALIDITY

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<tr>
<th></th>
<th>EB</th>
<th>HBR</th>
<th>HBV</th>
<th>HSB</th>
<th>HSR</th>
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<tr>
<td><strong>WORKLOAD DISCRIMINATION</strong></td>
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<tr>
<td>Differences between low and high workload flight?</td>
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<td>NO</td>
<td>NO</td>
<td>YES</td>
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<td>Low-high differences?</td>
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<tr>
<td>(7 possible)</td>
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### PHASE-OF-FLIGHT DISCRIMINATION

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<th>HBV</th>
<th>HSB</th>
<th>HSR</th>
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<tbody>
<tr>
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<td>YES</td>
<td>YES</td>
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<td>14</td>
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<td>7</td>
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<tr>
<td>(21 possible)</td>
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</table>

<table>
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<th>HBR</th>
<th>HBV</th>
<th>HSB</th>
<th>HSR</th>
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<td>Phase-of-flight differences?</td>
<td>6</td>
<td>9</td>
<td>10</td>
<td>1</td>
<td>0</td>
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<tr>
<td>(21 possible)</td>
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</table>

### RELIABILITY

<table>
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<th>HBV</th>
<th>HSB</th>
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<td>Test-retest correlations:</td>
<td>7</td>
<td>6</td>
<td>5</td>
<td>3</td>
<td>5</td>
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<tr>
<td>Day 1 to Day 2</td>
<td>(14 possible)</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>EB</th>
<th>HBR</th>
<th>HBV</th>
<th>HSB</th>
<th>HSR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inter-rater agreement:</td>
<td>56%</td>
<td>78%</td>
<td>44%</td>
<td>17%</td>
<td>28%</td>
</tr>
<tr>
<td>Each pilot to group average</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Notes

- **EB** -- Eye Blinks
- **HBR** -- Heart Beat Rate
- **HBV** -- Heart Beat Variability
- **HSB** -- Heart Spectra - Blood Pressure Component
- **HSR** -- Heart Spectra - Respiration Component

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PERFORMANCE DATA

Data from the simulator was collected during the measurement windows. Position information of the flight controls (wheel, column and pedals) were transformed into a measure of control activity labelled Control Input. In addition altitude over the outer and middle markers, flight director deviation, glideslope and localizer deviation, and lateral deviation from runway centerline was collected in the Approach and Landing windows. Since the measurement windows cover different lengths of time, the control activity is divided by units of time to yield the Control Input measure. This measure indicates the amount of significant control activity per minute. There was a strong indication that Control Input could discriminate between the two levels of workload.

If the pilot placed the plane on autopilot, the data for control position and consequently Control Input, was not collected. As a result there are measurement windows in the low workload condition which do not contain much data, making the comparison of low and high workload conditions meaningless from a statistical point of view. Even with the missing data, however, there is still a strong indication the Control Input can discriminate low and high workload conditions.

On the transparencies dots are used to denote a statistically significant relationship.

- On the chart including "means" for the workload measure the dot represents a significant difference between low and high workload for a given measurement window.
- On the chart including "correlation coefficients" for the workload measure the dot represents a significant correlation comparing test to retest for a given measurement window

Following are the transparencies presented on the analysis of the performance data.
PERFORMANCE MEASURES

- WHEEL CONTROL INPUTS
- STICK CONTROL INPUTS
- PEDAL CONTROL INPUTS
- SECONDARY TASK RESPONSE TIMES
- SECONDARY TASK PROBE RECOGNITION ACCURACY
WHEEL CONTROL INPUT

- WHEEL POSITION INFORMATION COLLECTED AT 10 hertz RATE
- 2.5% CHANGE FROM ONE DATA POINT TO THE NEXT INCREMENTS COUNTER
- VALUES PRESENTED PER UNIT TIME (WHEEL CONTROL INPUTS / MINUTE)
TEST–RETEST RELIABILITY
WHEEL CONTROL INPUTS

(DF ≥ 10)

LEGEND
- LOW WORKLOAD
- HIGH WORKLOAD

INTER-RATER RELIABILITY
NA% OF SUBJECTS AGREE WITH MEAN
STICK CONTROL INPUT

STICK POSITION INFORMATION COLLECTED AT 10 hertz RATE

2.5% CHANGE FROM ONE DATA POINT TO THE NEXT INCREMENTS COUNTER

VALUES PRESENTED PER UNIT TIME (STICK CONTROL INPUTS / MINUTE)
MEAN SCORES
STICK CONTROL INPUTS

LEGEND
- LOW WORKLOAD
- HIGH WORKLOAD

PHASE OF FLIGHT
DISCRIMINATION

LOW WORKLOAD NA/21
HIGH WORKLOAD 9/21
PEDAL CONTROL INPUT

- PEDAL POSITION INFORMATION COLLECTED AT 10 hertz RATE
- 2.5% CHANGE FROM ONE DATA POINT TO THE NEXT INCREMENTS COUNTER
- VALUES PRESENTED PER UNIT TIME (PEDAL CONTROL INPUTS / MINUTE)
MEAN SCORES
PEDAL CONTROL INPUTS

LEGEND
- LOW WORKLOAD
- HIGH WORKLOAD

PHASE OF FLIGHT
DISCRIMINATION
LOW WORKLOAD NA / 21
HIGH WORKLOAD 11 / 21

PEDAL CONTROL INPUTS PER MINUTE

WINDOWS

W1  W2  W3  W4  W5  W6  W7
33.4  3.3  2  1  0  0  30  29.5
TEST–RETEST RELIABILITY
PEDAL CONTROL INPUTS

(DF ≥ 10)

LEGEND
- LOW WORKLOAD
- HIGH WORKLOAD

INTER–RATER
RELIABILITY
NA % OF SUBJECTS
AGREE WITH MEAN

CORRELATION COEFFICIENT

W1
W2
W3
W4
W5
W6
W7

WINDOWS

-2
-1
0
1
2
3
4
5
6
7
8
9
10
SECONDARY TASK MEASURES

A secondary task was implemented to measure pilot's spare capacity (spare capacity is thought to be correlated with workload). The secondary task was a response time task. ATC would start a timer when they issued calls to aircraft designated as positive probes. The positive probe aircraft were the pilot's own aircraft or another aircraft in the area. All other aircraft were designated negative probes. The pilots pressed the push to talk switch on the left side of the yoke when they heard the call sign of the aircraft designated as positive probes and this stopped the timer ATC had activated. Two measures can be derived from the Secondary Task, response time and probe accuracy.

A post hoc examination of the accuracy of probe delivery indicates that ATC personnel did not deliver the probes in a consistent fashion across the different subjects. Also, responses which took longer than 10 seconds were disregarded because the task was not executed immediately. Even with all the flaws in the data collection there was a clear trend for a discrimination between the low and high workload conditions for Secondary Task Response Time. No clear trends for discriminating low and high workload are found for Probe Accuracy. A statistical analysis of the reliability measures is not possible for either Response Time or Probe Accuracy because of the discrepant sample sizes due to the flawed probe presentation.

On the transparencies dots are used to denote a statistically significant relationship.

- On the chart including "means" for the workload measure the dot represents a significant difference between low and high workload for a given measurement window.

- On the chart including "correlation coefficients" for the workload measure the dot represents a significant correlation comparing test to retest for a given measurement window.

Following are the transparencies presented on the analysis of the secondary task measure data.
SECONDARY TASK

- TWO 'FLIGHT NUMBERS' ARE DESIGNATED POSITIVE PROBES
  - PILOT'S OWN FLIGHT NUMBER (AMERICAN 247)
  - ANOTHER FLIGHT NUMBER (AMERICAN 241)

- PILOT IS INSTRUCTED TO RESPOND TO ATC CALL INVOLVING PROBES AS QUICKLY AND ACCURATELY AS POSSIBLE

- PILOT RESPONSE IS TO TOGGLE PUSH TO TALK SWITCH (PTT)

RESPONSE TIME

- LENGTH OF TIME IN SECONDS IT TAKES PILOT TO RESPOND TO PROBE
SECONDARY TASK

- TWO 'FLIGHT NUMBERS' ARE DESIGNATED POSITIVE PROBES
  - PILOT'S OWN FLIGHT NUMBER (AMERICAN 247)
  - ANOTHER FLIGHT NUMBER (AMERICAN 241)

- PILOT IS INSTRUCTED TO RESPOND TO ATC CALL INVOLVING PROBES AS QUICKLY AND ACCURATELY AS POSSIBLE

- PILOT RESPONSE IS TO TOGGLE PUSH TO TALK SWITCH (PTT)

PROBE ACCURACY

- PERCENTAGE OF PROBES NOT RESPONDED TO OUT OF TOTAL NUMBER OF PROBES
MEAN SCORES
SECONDARY TASKS PERCENTAGE OF PROBES
WITH NO RESPONSE

LEGEND
- LOW WORKLOAD
- HIGH WORKLOAD

PHASE OF FLIGHT
DISCRIMINATION
LOW WORKLOAD NA / 21
HIGH WORKLOAD NA / 21
TEST–RETEST RELIABILITY
SECONDARY TASKS PERCENTAGE OF PROBES WITH NO RESPONSE

LEGEND
- LOW WORKLOAD
- HIGH WORKLOAD

INTER-RATER RELIABILITY
NA % OF SUBJECTS AGREE WITH MEAN
### Performance Measures

#### Summary

<table>
<thead>
<tr>
<th>Validity</th>
<th>Wheel</th>
<th>Stick</th>
<th>Pedal</th>
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<tr>
<td>Workload Discrimination</td>
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<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Differences between low and high workload flight?</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Low-high differences? (7 possible)</td>
<td>5</td>
<td>4</td>
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<td>1</td>
<td>0</td>
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<tr>
<td>Phase-of-flight Discrimination</td>
<td>N/A</td>
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<td>N/A</td>
<td>N/A</td>
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<tr>
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<td>N/A</td>
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<tr>
<td>Differences between phase-of-flight? (high)</td>
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<td>YES</td>
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<tr>
<td>Phase-of-flight differences? (21 possible)</td>
<td>10</td>
<td>9</td>
<td>11</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

#### Reliability

| Test-retest correlations: | 11 | 10 | 6 | 1 | 0 |
| Day 1 to Day 2 (14 possible) | |

| Inter-rater agreement: | N/A | N/A | N/A | N/A | N/A |
| Each pilot to group average |
ANALYTIC ASSESSMENT TECHNIQUE

The analytic assessment technique used was Time Line Analysis (TLA). TLA computes the ratio of time required, that is, execution time, to time available throughout a mission scenario.

TLA provides the capability to analyze complete operating scenarios in which one or more operators perform specified procedures, each of which is a sequence of individual tasks, within specified time intervals, over a prolonged period of time. Visual, manual, verbal, auditory and cognitive workload estimates are made for each task, procedure, phase and for the entire scenario. Analysis was performed on the Captain's tasks only.

The Time Line Analysis task was used to identify high and low task demand levels. For instance, all TLA channels (visual, manual, auditory, verbal and cognitive) showed a higher workload level in the climb phase of flight when the autopilot failed to engage. When the engine and hydraulic systems failed, a higher level of workload was again reflected by TLA. This higher workload level then continued through the rest of the high workload flights because the pilot was handflying the aircraft with the failure conditions to a high speed landing. In contrast, task demands in the takeoff segment of flight for all scenarios were identical, so the workload level for the takeoff segment was hypothesized to be the same for both the high and low workload scenarios.

As shown by the data, TLA accurately reflects the task demands of the scenarios. TLA can be a very useful tool to identify periods of high and low task demands.

Following are the transparencies presented on the Time Line Analysis assessment performed.
Analytical Workload Measurement

Timeline Analysis

Aileen L. Logan
Boeing Commercial Aircraft Company
Seattle, Washington
Timeline Analysis (TLA)

Computes the ratio of time required to time available throughout the flight mission scenario.
Timeline Analysis
Geometric Data Base

- Index/control records
  - Number of panels
  - Number and types of controls and indicators
  - Control and indicator type descriptions
  - Eye, look, and hand reference points
  - Auditory message count and type
  - Verbal message types and type descriptions

- Panel configuration records
  - Control and indicator data
Flight Deck Geometric Data Base
Timeline Analysis
Flight Deck Geometric Data Base
Boeing 727-232 (Delta)
Timeline Analysis
Flight Deck Geometric Data Base
Boeing 727-232 (Delta)
Timeline Analysis
Example of Flight Mission Scenario File

CR  1 Captain
FP  1 Takeoff
PR  0001.30  Start takeoff run  0001.30  0001.45
ST  
  • Hears brake lever release
  • Senses airplane start to roll
  • Advances thrust levers for number 1 engine
     for initial acceleration and allows
     even engine spoolup
  • Advances thrust levers for number 2 engine
     for initial acceleration and allows
     even engine spoolup
  • Looks at engine EPR indicators
     for even engine acceleration (engines 1, 2, and 3)
  • Continues thrust levers
     to approximate takeoff setting (engines 1, 2, and 3)
  • Check engine EPR indicators for
     takeoff bug setting (engines 1, 2, and 3)
  • Sees F/O adjust thrust levers for number 1, 2, and 3 engines
Timeline Analysis (Continued)
Example of Flight Mission Scenario File

- Looks through left front window along runway centerline
- Maintains light forward pressure on column
- Keeps wings level
- Hears F/O “80 kn”
- Looks at airspeed display
- Says, “Check”
- Continues looking out forward window

CD  8101, 13201, 7104, 7204, 239, 235, 7111, 7211, 239, 235, 7111S, 7211S, 13302, 180,
    13302, 30004, 114, 20004, 13302

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<th>PR</th>
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<tr>
<td>ST</td>
<td></td>
<td></td>
<td></td>
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</table>
<pre><code>|         | • Hears F/O “V one” |         |         |
|         | • Hears F/O, “Rotate” |         |         |
|         | • Looks at airspeed |         |         |
|         | • Begins to apply back force on control wheel |         |         |
|         | • Rotates to liftoff attitude |         |         |
|         | • Complete rotation to desired attitude with reference to attitude indicator |         |         |
|         | • Senses liftoff |         |         |
|         | • Checks altimeter for positive rate of climb |         |         |
</code></pre>
Timeline Analysis

Time Requirements

Hand Movement Time Used in SWAT

Left to Right

Right to Left

Inward-Outward

Time, sec

0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

Length of Movement

Horizontal Positioning Movements

Versus Length of Movement

0, Eye Angle Change, deg

Eye Motion Versus Angle-of-Eye-Movement Change

T = 0.021θ²/5

Time, sec

0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08

cm

0
2.5
5
10
15
20
25
30
35
40

in

0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
Timeline Analysis

- Evaluates for each crew member:
  - Hand activity time
  - Eye activity time
  - Cognition time

- Estimates the times a crew member is occupied by:
  - Visual task
  - Motor task
  - Cognitive task
  - Verbal task
  - Auditory task
Timeline Analysis

- Requires
  - Flight deck geometric data base
    - Complete task code data
    - Complete hand and eye reference point data
  - Flight mission scenario file
    - Detailed task breakdown for full flight
Timeline Analysis
Crew Station Description, Example

Each device is characterized in terms of its:
- Aircraft location
- Workload cost (dwell time)
- Complexity score

Workload Cost Table (Example)

<table>
<thead>
<tr>
<th>Estimated Workload Cost (Dwell Time, sec)</th>
<th>Workload Type Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.04 CIRCULAR SCALE GAUGES (QUANTITATIVE READING)</td>
<td>13</td>
</tr>
<tr>
<td>3.30 CIRCULAR SCALE VALVE POSITION</td>
<td>14</td>
</tr>
<tr>
<td>3.67 LINEAR SCALE</td>
<td>15</td>
</tr>
<tr>
<td>1.50 DIGITAL INDICATOR</td>
<td>16</td>
</tr>
<tr>
<td>0.75 MONITOR SWITCH POSITION</td>
<td>17</td>
</tr>
<tr>
<td>2.73 CIRCULAR SCALE GAUGES (QUALITATIVE READING)</td>
<td>18</td>
</tr>
</tbody>
</table>

Example Data Card Format

<table>
<thead>
<tr>
<th>8208</th>
<th>1</th>
<th>7</th>
<th>2.20</th>
<th>0.38</th>
<th>1.58</th>
<th>PRESSURE MODE SEL MONITOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Device Code</td>
<td>Workload Type Code</td>
<td>Location Coordinates</td>
<td>Complexity Score (bits)</td>
<td>Device Description</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

BL1167.04
## Timeline Analysis
### Device Complexity Measure

<table>
<thead>
<tr>
<th>Definition</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Device complexity is the number of binary digits required to encode the possible number of alternatives associated with the device</td>
<td>Instrument Reading</td>
</tr>
<tr>
<td></td>
<td>Number of Alternatives = ( \frac{\text{Range}}{(0.5)(\text{Scale Unit})} )</td>
</tr>
<tr>
<td></td>
<td>Device Complexity = ( \log_2 \left( \frac{10}{(0.5)(1)} \right) = 4.35 \text{ bits} )</td>
</tr>
<tr>
<td></td>
<td>Discrete Control</td>
</tr>
<tr>
<td></td>
<td>Number of Alternatives = 5</td>
</tr>
<tr>
<td></td>
<td>Device Complexity = ( \log_2 (5) = 2.32 \text{ bits} )</td>
</tr>
</tbody>
</table>

Device Complexity = \( \log_2 (\text{Number of Alternatives}) \) bits
Timeline Analysis
Device Complexity Measure

- Device complexity score is based upon the information content of the possible states that the device presents.

- The device complexity score serves as the basis for estimating cognitive workload time.

- Procedure complexity is the sum of device complexity scores for all steps of a procedure.
Timeline Analysis
Workload Measures

- **Motion**
  - Eyes - Total degrees traveled
  - Hands - Total inches traveled

- **Time**
  - Total time to execute task (transit + dwell)

- **Tasks**
  - Number of actions required to execute a task

- **Procedure**
  - Summation of device complexity associated with a task
When observer looks at an object point above the ERP, rotation is at the head pivot point. Below the ERP, rotation is at the shoulder pivot point.
Timeline Analysis

Percent of Window Time = \frac{\text{Time Used}}{\text{Length of Window}}

Low Workload Data = \frac{(\text{Low SMF to SFO}) + (\text{Low SFO to SCK})}{2}

High Workload Data = \frac{(\text{High SMF to SFO}) + (\text{High SFO to SCK})}{2}
Timeline Analysis
Visual Data

Percent of Window Time

Data Collection Window

Takeoff  Climb  Cruise 1  Cruise 2  Descent  Approach  Landing

Color Code
- Low
- High

EL1167.05
Timeline Analysis
Manual Data

Color Code
- Manual Sum (Low)
- Manual Right (Low)
- Manual Left (Low)
- Manual Sum (High)
- Manual Right (High)
- Manual Left (High)

Percent of Window Time

Data Collection Window

Takeoff  Climb  Cruise 1  Cruise 2  Descent  Approach  Landing
Timeline Analysis
Verbal Data

Data Collection Window

Percent of Window Time

Takeoff  Climb  Cruise 1  Cruise 2  Descent  Approach  Landing

Color Code
- Low
- High

EL1167.03
Timeline Analysis

Auditory Data

Color Code
- Low
- High

Percent of Window Time

Data Collection Window

Takeoff  Climb  Cruise 1  Cruise 2  Descent  Approach  Landing
Timeline Analysis
Cognitive Data

Color Code
- Low
- High

Data Collection Window
COMPARISON OF WORKLOAD MEASURES
DESCRIPTION OF CORRELATION MATRIX AND FACTOR ANALYSIS

A correlation matrix was created for all the workload assessment techniques presented at the workshop including: subjective, physiological, performance, and time-line analysis. The average score across subjects for the 14 different measurement periods (seven measurement windows for the high and low workload flights) were used for the correlation matrix. The time-line analysis yields a single score, for each body channel, for each of the 14 measurement windows. The workload scores were then used to compute the correlation matrix.

The purpose of the correlation matrix is to evaluate how much the workload scores "overlap". If two workload measures can both discriminate levels of workload and show reliability but are not correlated then the two measures are thought to be evaluating different aspects of workload.

In addition to the correlation matrix a principal components analysis (factor analysis) was performed to try to reveal underlying common dimensions among the various workload measures. The same 14 measurement window were used for the principal components analysis. A "loading" for the factor analysis is a number between 1.0 and -1.0. The factor loading can be thought of in terms of an absolute value in that a score of 0.85 or -0.85 loads highly on the given factor. The closer the factor loading is to zero the less that particular workload assessment technique is associated with the given factor (factor loadings between 0.25 and -0.25 are intentionally left blank).

In addition to the correlation matrix, the factor analysis can show that two different valid and reliable workload measures assess different aspects of workload. If the workload measures show validity and reliability but load on different factors in the factor analysis, it indicates the measures are tapping different aspects of workload.
**CORRELATION MATRIX**

<table>
<thead>
<tr>
<th></th>
<th>HRM</th>
<th>HRSD</th>
<th>ABP</th>
<th>ARS</th>
<th>EBK</th>
<th>WHL</th>
<th>STK</th>
<th>PDL</th>
<th>SWAT</th>
<th>TLX</th>
<th>STRT</th>
<th>STRT%</th>
</tr>
</thead>
<tbody>
<tr>
<td>HRM</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>HRSD</td>
<td>-.58</td>
<td>1.00</td>
<td></td>
<td></td>
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<tr>
<td>ABP</td>
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<td>ARS</td>
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<tr>
<td>EBK</td>
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<tr>
<td>PDL</td>
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<td>-.54</td>
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<td>.17</td>
<td>.47</td>
<td>1.00</td>
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<td></td>
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<tr>
<td>SWAT</td>
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<td>.68</td>
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<td>1.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TLX</td>
<td>-.32</td>
<td>.37</td>
<td>.07</td>
<td>.62</td>
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<td>.51</td>
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<td>.60</td>
<td>.57</td>
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<tr>
<td>STRT%</td>
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<td>.09</td>
<td>-.43</td>
<td>.18</td>
<td>-.25</td>
<td>.46</td>
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<td>-.05</td>
<td>.54</td>
<td>.49</td>
<td>.35</td>
<td>1.00</td>
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<tr>
<td>VISUAL</td>
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<td>-.91</td>
<td>-.05</td>
<td>-.11</td>
<td>.34</td>
<td>.38</td>
<td>.54</td>
<td>.04</td>
<td>-.02</td>
<td>-.39</td>
<td>.48</td>
</tr>
<tr>
<td>MANLEFT</td>
<td>-.64</td>
<td>.10</td>
<td>-.87</td>
<td>.12</td>
<td>-.03</td>
<td>.36</td>
<td>.43</td>
<td>.59</td>
<td>.05</td>
<td>.03</td>
<td>-.41</td>
<td>.19</td>
</tr>
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<td>MANRIGHT</td>
<td>-.56</td>
<td>.54</td>
<td>-.39</td>
<td>.32</td>
<td>.11</td>
<td>.55</td>
<td>.60</td>
<td>.39</td>
<td>.49</td>
<td>.40</td>
<td>.14</td>
<td>.51</td>
</tr>
<tr>
<td>VERBAL</td>
<td>-.17</td>
<td>-.13</td>
<td>-.04</td>
<td>.11</td>
<td>-.39</td>
<td>.09</td>
<td>-.13</td>
<td>-.47</td>
<td>.51</td>
<td>.63</td>
<td>.03</td>
<td>.31</td>
</tr>
<tr>
<td>AUDITORY</td>
<td>.14</td>
<td>-.13</td>
<td>-.44</td>
<td>-.08</td>
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<td>.15</td>
<td>-.07</td>
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<td>.21</td>
<td>.28</td>
<td>-.13</td>
<td>.51</td>
</tr>
<tr>
<td>COGN’TVE</td>
<td>-.02</td>
<td>-.31</td>
<td>-.66</td>
<td>-.26</td>
<td>-.42</td>
<td>-.01</td>
<td>-.12</td>
<td>-.04</td>
<td>.20</td>
<td>.25</td>
<td>-.32</td>
<td>.55</td>
</tr>
</tbody>
</table>

**VISUAL** -- Eyes
**MANLEFT** -- Left side of body
**MANRIGHT** -- Right side of body
**VERBAL** -- Spoken communication
**AUDITORY** -- Listening by flight crew
**COGN’TVE** -- Cognitive channel

---

**VISUAL** 1.00
**MANLEFT** .74 1.00
**MANRIGHT** .64 .28 1.00
**VERBAL** .10 -.01 .21 1.00
**AUDITORY** .55 .25 .38 .78 1.00
**COGN’TVE** .65 .42 .49 .65 .85 1.00

***Critical correlation values are r(12)=.66 or r(12)=-.66 are in bold***

**VARIABLE LABELS**

- **HRM**: Average Inter-beat Interval
- **HRSD**: Standard Deviation for Average Inter-beat Interval
- **ABP**: Mulder Spectral Analysis Blood Pressure component from heart rate
- **ARS**: Mulder Spectral Analysis Respiration component from heart rate
- **EBK**: Eye blinks per minute
- **WHL**: Wheel control input (ailerons) per minute
- **STK**: Stick control input (ailerons) per minute
- **PDL**: Pedal control input (ailerons) per minute
- **SWAT**: Subjective Workload Assessment Technique
- **TLX**: NASA Task Load Index
- **STRT**: Secondary Task Reaction Time
- **STRT%**: Probe Accuracy, to positive probes, for Secondary Task

---

**BOEING TIME-LINE ANALYSIS**

- **VISUAL** -- Eyes
- **MANLEFT** -- Left side of body
- **MANRIGHT** -- Right side of body
- **VERBAL** -- Spoken communication
- **AUDITORY** -- Listening by flight crew
- **COGN’TVE** -- Cognitive channel

---

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PRINCIPAL COMPONENT ANALYSIS

SORTED ROTATED FACTOR LOADINGS (PATTERN)

<table>
<thead>
<tr>
<th></th>
<th>FACTOR</th>
<th>FACTOR</th>
<th>FACTOR</th>
<th>FACTOR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>RESPIRATION 4</td>
<td>.938</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WHEEL INPUT 6</td>
<td>.936</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>STICK INPUT 7</td>
<td>.870</td>
<td>.357</td>
<td></td>
<td>.346</td>
</tr>
<tr>
<td>HR VARIABILITY 2</td>
<td>.826</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SWAT 9</td>
<td>.753</td>
<td></td>
<td>.527</td>
<td></td>
</tr>
<tr>
<td>SEC. TASK RT 11</td>
<td>.706</td>
<td>-.545</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TLX 10</td>
<td>.676</td>
<td></td>
<td>.580</td>
<td></td>
</tr>
<tr>
<td>HR AVG. IBI 1</td>
<td>-.627</td>
<td>-.626</td>
<td></td>
<td>-.301</td>
</tr>
</tbody>
</table>

BLOOD PRESS. 3           |        | -.929  | -.281  |
MANUAL LEFT 14           |        | .913   |        |        |
VISUAL 13                |        | .887   | .367   |        |
PEDAL INPUT 8            |        | .664   | -.284  | .656   |

COGNITION 18             |        | .437   | .845   |        |
VERBAL 16                |        |        | .837   |        |
AUDITORY 17              |        | .253   | .836   | -.274  |
SEC. TASK % 12           |        | .306   | .674   |        |
MANUAL RIGHT 15          |        | .427   | .371   | .517   | .453   |

EYEBLINK 5               |        |        | -.318  | .867   |

VP 5.502 4.333 3.898 1.851

The above factor loading matrix has been rearranged so that the columns appear in decreasing order of variance explained by the factors. The rows have been rearranged so that for each successive factor, loadings greater than 0.500 appear first. Loadings less than 0.25 have been blanked.
Description of Full-Mission Simulation Testing

Diane L. Sandry-Garza
Boeing Commercial Airplane Company
Seattle, Washington
Schedule
Full-Mission Simulation
Testing at NASA-Ames

1987
Oct 19 20 Nov

1988
Dec 11 12 Jan

Feb

Session 1:
(Test)

Session 2:
(Retest)
Simulation Facility

- NASA - Ames (MVSRF)
- Boeing 727 motion-base simulator
- High level of fidelity
- ATC simulation
Subjects

- FAR qualified and current 727 airline pilots
- Captain (data collection)
- Confederates
- Representative of population
Full-Mission Simulation Scenarios
(Short Legs)

F/O Incapacitation

Low/Normal
Full-Mission Simulation
Phases of Flight and Data Collection
(Short Leg)

<table>
<thead>
<tr>
<th>Phase of flight, min</th>
<th>Data collection windows, min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Takeoff 2.7</td>
<td>Flaps 5</td>
</tr>
<tr>
<td>Climb 3.25</td>
<td></td>
</tr>
<tr>
<td>Cruise 7.0</td>
<td></td>
</tr>
<tr>
<td>Descent 7.5</td>
<td></td>
</tr>
<tr>
<td>Approach 4.7</td>
<td></td>
</tr>
<tr>
<td>Landing 1.5</td>
<td></td>
</tr>
<tr>
<td>Localizer Alive (2 dots)</td>
<td></td>
</tr>
<tr>
<td>Passes Middle Marker</td>
<td></td>
</tr>
<tr>
<td>Ground Speed &gt; 5 Up</td>
<td></td>
</tr>
<tr>
<td>1 min After 10,000 ft</td>
<td></td>
</tr>
<tr>
<td>Pulls No. 2 Thrust Lever to Idle</td>
<td></td>
</tr>
</tbody>
</table>
# Full-Mission Simulation
(Short Legs)

## Data Collection Windows

<table>
<thead>
<tr>
<th>Window</th>
<th>Open</th>
<th>Close</th>
</tr>
</thead>
<tbody>
<tr>
<td>Takeoff</td>
<td>E.P.R. 1.50</td>
<td>Flaps 5</td>
</tr>
<tr>
<td>Climb</td>
<td>Flaps up</td>
<td>1 min later</td>
</tr>
<tr>
<td>Cruise 1</td>
<td>1 min after 10,000 ft</td>
<td>2 min later</td>
</tr>
<tr>
<td>Cruise 2</td>
<td>3 min after window 3 closes</td>
<td>2 min later</td>
</tr>
<tr>
<td>Descent</td>
<td>Number 2 throttle to idle</td>
<td>2 min later</td>
</tr>
<tr>
<td>Approach</td>
<td>Localizer alive (2 dots)</td>
<td>Outer marker</td>
</tr>
<tr>
<td>Landing</td>
<td>Middle marker</td>
<td>30 sec later</td>
</tr>
</tbody>
</table>
Full-Mission Simulation Scenario
(High Workload Leg)
# Full-Mission Simulation

## (High Workload Leg)

<table>
<thead>
<tr>
<th>Window</th>
<th>Open</th>
<th>Close</th>
</tr>
</thead>
<tbody>
<tr>
<td>Takeoff</td>
<td>E.P.R. 1.50</td>
<td>Flaps 5</td>
</tr>
<tr>
<td>Climb</td>
<td>Flaps up</td>
<td>1 min later</td>
</tr>
<tr>
<td>Cruise 1</td>
<td>1 min after 30,000 ft</td>
<td>2 min later</td>
</tr>
<tr>
<td>Cruise 2</td>
<td>3 min after window 3 closes</td>
<td>2 min later</td>
</tr>
<tr>
<td>Descent</td>
<td>Number 2 throttle to idle</td>
<td>2 min later</td>
</tr>
<tr>
<td>Approach</td>
<td>Localizer alive (2 dots)</td>
<td>Outer marker</td>
</tr>
<tr>
<td>Landing</td>
<td>Middle marker</td>
<td>30 sec later</td>
</tr>
<tr>
<td>Missed approach</td>
<td>1,500 ft after middle marker</td>
<td>2 min later</td>
</tr>
<tr>
<td>“A” System hydraulic malfunction</td>
<td>1 min after 6,800 ft</td>
<td>Outer marker</td>
</tr>
<tr>
<td>Approach</td>
<td>Localizer alive (2 dots)</td>
<td>30 sec later</td>
</tr>
<tr>
<td>Landing</td>
<td>Middle marker</td>
<td></td>
</tr>
</tbody>
</table>

Data Collection Windows

D1167.03
## Full-Mission Simulation

### Workload Levels

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Weather</th>
<th>Wind</th>
<th>Non-normals</th>
</tr>
</thead>
</table>
| High       | LAX: Ceiling 500 ft, visibility, 3 mi; OAK: Ceiling 200 ft, RVR zero; SMF: Clear, visibility 15 mi | LAX: Calm; OAK: Calm; SMF: 340 at 10 km | • "A" system hydraulic low pressure light illuminated  
• Number three engine flameout  
• Hydraulic system "A" failure |
| Low        | Clear   | Calm | None        |
| Incapacitation (SMF → SFO) | Clear | Calm | F/O Incapacitation |

### Key Details
- **High Level Conditions:**
  - LAX: Ceiling 500 ft, visibility, 3 mi
  - OAK: Ceiling 200 ft, RVR zero
  - SMF: Clear, visibility 15 mi
- **Low Level Conditions:**
  - Clear
- **Incapacitation (SMF → SFO):**
  - Clear, Calm
  - F/O Incapacitation
Operationally Relevant Types of Workload
FAR 25.1523, Appendix D

- FAA addresses
  - 6 workload functions
  - 10 workload factors

- Map FAR-25 function and factor descriptions into scenarios

- Divide scenarios into high and low workload levels based on objective task demands
Basic Workload Functions

FAR-25

1. Flightpath control
2. Collision avoidance
3. Navigation
4. Communications
5. Operations and monitoring of aircraft engines and systems
6. Command decisions
Workload Factors
FAR-25

1. Controls
2. Displays
3. Procedures
4. Mental and physical effort
5. Monitoring
8. Communication and navigation

9. Nonnormals
6. Crew member out of area
7. Automation breakdown
10. Incapacitated crew member
## Function and Factor Mapping Example

<table>
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<tr>
<th>Function</th>
<th>Factor</th>
<th>Time</th>
<th>Event</th>
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<tr>
<td>4,5,6</td>
<td>3,8A</td>
<td>00:02:15</td>
<td>Gear Retract - Start Initial Climb</td>
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<tr>
<td>4</td>
<td>8A</td>
<td></td>
<td>- Calls, &quot;gear up&quot;</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td></td>
<td>- Hears F/O, &quot;gear up&quot;</td>
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<tr>
<td>1,5</td>
<td>2,3,5</td>
<td></td>
<td>- Sees F/O compliance (peripheral vision)</td>
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<tr>
<td>1,5,6</td>
<td>1,2,3</td>
<td></td>
<td>- Looks to see if airspeed stabilized at approximately ( V2 + 10 )</td>
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<tr>
<td>1,5,6</td>
<td>1,2,3</td>
<td></td>
<td>- Adjusts pitch attitude to maintain ( V2 + 10 ) if necessary</td>
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<tr>
<td></td>
<td></td>
<td>00:02:35</td>
<td>Cleared Direct Sacramento Vortac</td>
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Dependent Measures

- Subjective
- Physiological
- Performance
- Task timeline analysis
Dependent Measures

- Subjective
  - NASA TLX
  - SWAT

- Physiological
  - Heart rate variability
  - Eye blinks
  - Eye movement

- Performance
  - Primary task
  - Secondary task

- Analytical
  - Task timeline analysis
Subjective Measures

- Subjective workload assessment technique (SWAT)
- Task load index (TLX)
- Overall workload score (simple 20-point scale)
Subjective Measures

- Inflight (direct measurement)
- Postflight (videotape)
- Example measures
- NASA TLX
- SWAT
Physiological Measures

- Eyeblink rate
- Eye movement
- Heart
  - Rate
  - Rate variability
- Heart spectral analysis
  - Blood pressure component
  - Respiration component
Performance Measures

- Primary Task
  - Reversals
    - Stick
    - Aileron
  - Rudder
  - Throttle

- Approach and landing
  - Flightpath error
  - Glideslope and localizer variability
  - Altitude at outer, middle, and inner markers

- Secondary Task
  - Sternberg RT task
Secondary Task

- Two "flight numbers" are designated positive probes
- Pilot's own flight number (United 247)
- Another aircraft flight number (United 241)
- Pilot is instructed to respond as quickly and accurately as possible
- Pilot response is to toggle "push to talk" switch
Secondary Task Measures

- Probe accuracy
- Response time
Task Timeline Analysis (TLA)

- Selected segments
- Proven TLA method
- Identifies high and low task-demand levels
- Validity of workload measures against proven tool
# Full-Mission Simulation

## Experimental Design

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DISCUSSION

SUMMARY POINTS

IMPLEMENTATION OF A UNIDIMENSIONAL WORKLOAD MEASURE:
The feasibility of using a unidimensional workload scale, in addition to the other subjective measures taken, was discussed. The possibility of using a "Modified Cooper-Harper" or the "Bedford Scale" was addressed. The Bedford Scale is a measure of spare capacity. Some felt the pilots have trouble assessing their "spare capacity". The Bedford Scale is used extensively in the European community, and the FAA showed a great interest in having it assessed during full-mission testing. The Bedford Scale would be administered post-flight with the use of video tapes.

IN-FLIGHT RATING ISSUE:
Should the use of in-flight ratings be incorporated in full-mission simulation? A number of suggestions were made to include an in-flight subjective measure to provide opportunity for a comparison of in-flight versus post-flight subjective assessment. The discussion included the question of which rating scale could be employed in the particular scenarios already built for full-mission testing. SWAT scores can be taken verbally and will work in the given scenarios. The workload involved in these scenarios precludes the use of a "clipboard" by the pilot to give his ratings. Correct administration of NASA's TLX requires a "clipboard" approach. The question of when these ratings would be taken in-flight was also raised. If the ratings are requested at the end of the measurement windows, then pilots may learn where the measurements are being taken. This needs to be avoided as the pilot might change his performance (i.e., try harder or be better) at specific times because he knows he is being measured. It was suggested that measurements be taken at variable intervals, both during and outside of measurement windows. A final point was made that if, in fact, SWAT ratings are taken "at the moment" of the window closing then the scores given may reflect only the workload at that particular moment and not the workload of the whole measurement period (i.e., the measurement window).

SECONDARY-TASK ADMINISTRATION:
The problems that occurred with application of the secondary-task measure during the part-task simulation were discussed. The switch used by the pilot to respond to the positive probes blanked ATC with the switch closure. The feasibility of using a different switch was discussed. A suggestion was made to use verbal responses. It was concluded that voice relay is not a feasible alternative in the noisy cockpit environment. The noises often trigger the switch relay, and the variability using this technique is extremely high. The design of the secondary task was discussed in length. Many felt the secondary task technique couldn't be used in the flight test portion of certification. It was determined, however, that the secondary task may be valuable even if it can only be used in simulation. Even though it was handicapped during the part-task testing by problems that were encountered, it's data showed great promise. The problems that occurred in part-task can be controlled in full-mission testing. Several other types of tasks were suggested for use as a secondary task measure; however, they lacked the requirements of the secondary task to have both positive and
negative probes and to have the probes occur often enough to gather a good base of data. Since data is collected on the Captain only, the task must also be one that is normally performed by the Captain. The Boeing and Douglas team members working this contract are currently evaluating all alternatives.

**USE OF AUTOPILOT ISSUE:**

Autopilot implementation during part-task simulation was discussed. In part-task testing, the use of autopilot was left to the pilot's discretion, and thus, its use became inconsistent across the subject population. It was felt that a tighter control on the use of autopilot (or preventing its use altogether) in full mission testing should be required. Various ways to accomplish this were discussed, such as incorporating additional autopilot training into differences training or using the confederates in the cockpit to aid in consistency of use. It was suggested that if the autopilot could be an MEL item for all legs, there would be no chance of inconsistency among subjects. It was agreed that for full-mission testing the autopilot would be MEL for all legs.

**INCAPACITATION ISSUE:**

It was submitted that during full-mission simulation testing the first officer might be incapacitated during one leg of the scenario. The question was raised whether the first-officer is being incapacitated in order to study the "incapacitation" issue or to manipulate the Captain's communications workload. A discussion on which approach is more relevant for certification ensued. If the question is, in fact, "can the measures detect changes in increased communications (e.g., radio communications)?" then an "incapacitation" scenario may not be the best alternative. An incapacitation introduces a large and complex set of task demands. It may be better, in fact, to introduce a specific set of task demands (e.g., radio communications) to be the Captain's assigned task in addition to his normal duties. This discussion included the considerations that must be made for all phases of certification. For instance, if an incapacitation scenario is used, where does incapacitation of the first officer occur (i.e., in what phase of flight), how are the airline procedural differences in handling an incapacitation accounted for, and when incapacitated, is the first officer removed from his seat? Both issues, incapacitation and communications workload, cover workload factors of FAR 25, Appendix D, which were not manipulated in the part-task study. The Boeing/Douglas team working this contract is evaluating all possibilities.
WRITTEN COMMENTS PROVIDED BY ATTENDEES

WORKSHOP #2

FULL-MISSION SIMULATION SUGGESTIONS

1. For incapacitation you could try the following:
   A. Captain says "I have briefed flight attendants, the F/O is being cared for by a physician, ATC has been advised, EMS is standing by, you will be vectored with priority. Also, company has been advised."
   B. Have Preston suggest, "You look tied, why don't you use the autopilot?" As a means of standardizing autopilot use.
   C. Keep your high workload profile as it is. I believe it will measure sensitivity at high levels.

2. Use simple scale (say Bedford or Airbus) during flight.

3. Do TLX post flight.

4. Drop SWAT on the assumption that it correlates well with TLX.

5. Draw the pilots from a:
   - single carrier
   - 2 carriers and balanced
   - 3 carriers and balanced.

6. Certification would take the autopilot being an MEL item on all flights.

7. SWAT did well on high workload, so do a regression TLA-SWAT check correlation. Use weights for the next simulation.

8. In your study, you used visibility and wind conditions to manipulate workload levels. However, as I understand it, TLA does not take these conditions into account. Consequently, how can you use TLA as your baseline metric?

9. It seems that a lot of confounds occurred due to pilot training in dealing with anomalous situations. Some pilots dealt with emergencies singlehandedly whereas others delegated tasks to other crewmembers. Consequently, your data represented different types as well as levels of workload. During full mission simulation, you may want to impose stringent operation procedures in order to control for some of these confounds.

10. It makes sense that workload should be consistent as possible within bounds of "normal" operations. It does not make sense to try to combine workload measures for pilots who use autopilot and those who do not.
11. Since (a) you have a small "N" and (b) dispatch with autopilot inoperable is accepted by the MEL, why not use a "failed" autopilot in your tests.

12. I recommend that your experimental procedures be reviewed to maximize the degree of task and task load commonality within the bounds of "normal" operations.

13. If a secondary task is used, why not consider realism of task demand as one of the criteria? This may not be feasible for available secondary task list, but the concept deserves consideration.

14. You have a two crew- three crew source of confusion between earlier and present test plans. Accordingly, even though you plan emphasis on a two crew operation in coming tests, why not start the flight with three than "disable" one. This would establish a connecting link between the two series of tests as a meaningful basis for comparison across tests.

15. Did the analytical (TLA) approach include the variations in degraded modes of operation? If not, a higher degree of correlation might be found between analytic and empirical results.

16. Discussions indicate you are considering changing applications of tools (e.g., SWAT may be used in flight when it was earlier used post flight). When the conditions of application are not the same, there is a high likelihood that subtle differences in results will occur. Context dependency cannot be ruled out, as thousands of graduate students found out in studies of semantic differential. Also, there is a strong possibility the "inflight" ratings, will be remembered to some degree and have an influence on "post flight" ratings.

17. I am concerned that we are measuring (or attempting to measure) pilots reaction to changes that affect the tasks he must perform. We choose to call this reaction "workload". The experimental design you have chosen, changes the tasks the crew must perform, as a function of the scenario and introduction of malfunctions. What it appears you wish to address is changes in configuration (from a base line aircraft "A" to a new configuration "B"), and those affects, reaction of the task, workload. Also you may want to address changes in crew size, crew training, procedures, environment, etc.

My concern is the level of reaction that we measure as a result of malfunctions introduction into a mission, may have very little, if any, correlation to other changes, such as crew station configuration, crew size, etc. Research must be conducted to determine if the measure that is sensitive to one change is still a reliable measure for other changes that affect crew tasks and are seen in measurable, significant change in workload.

18. The point that was made in regard to the coarseness of the sensitivity of the parameters to detect workload is well taken. Simply because the parameters chosen can distinguish increases in workload during anomalous conditions, it does not follow that they can detect subtle changes in workload. Granted, one must investigate the capability to detect coarse events initially, but you need to go one step further in your full mission simulation. For example, introducing poorly designed display formats which are known to increase workload might be an approach to further defining the sensitivity level of the parameters that have been chosen.
USAF/FAA REVIEW OF WORKLOAD MEASUREMENT METHODS:
PART-TASK SIMULATION DATA SUMMARY WORKSHOP

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