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OPERATIONAL NEED

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2.1 PILOT SURVEY

Between April 1997 and October 1998, Working Group #27 conducted discussions with experienced military fighter pilots and test pilots concerning the human factor implications of agile aircraft flight. Aircrews interviewed included 23 U.S. pilots (consisting of 5 NASA Test Pilots, 13 USAF Air Warfare Center Pilots, and 5 USAF Pilot-Physicians), 11 Swedish Air Force operational pilots, 3 German Air Force test pilots, and 2 French pilots. After the discussions, the aircrews were asked to complete an anonymous questionnaire. (Note, the French pilots were interviewed before the questionnaire was completed and so their views are represented in the pilot comments, but not in the actual questionnaire results.) In addition to the questionnaire results, one-on-one interviews were conducted with many of the pilots. A world wide representation of most agile aircraft was achieved by surveying pilots experienced with the X-31, F-18 HARV, F-15 Active, MATV, Harrier, F-22, F-18, MIG-29, Rafale, Gripen, and Eurofighter.

As a part of the questionnaire, the aircrew members were asked background questions concerning their flying experience. The remainder of the questionnaire involved rating the utility of various aircraft capabilities (e.g., high AOA/post-stall maneuvering, negative G maneuvering, high (+12) Gz maneuvering) with regard to their contribution to air-to-air combat performance. A seven point scale was used to rate the perceived contributions to air combat effectiveness. Specifically, ratings ranged from 1 for "Not at all useful", 3 for "Slightly useful", 5 for "Moderately useful", to 7 for "Very useful."

The aircrews were, on the average, very experienced with an average flying time of 2,589 hours (range 900-9,000). A summary of the ratings for agility factors in shown in Table 2.1. Note that some pilots did not have experience with helmet mounted sights or advanced anti-G suits. Hence, they did not rate these systems. Combat Edge (the USAF positive pressure breathing system for G protection) and the Advanced Technology Anti-G suit were included as known benchmarks against which to judge the pilot responses.

Pilots rated helmet-mounted sights, high AOA maneuvering, and high G capability all highly. Ratings of negative Gs varied widely among the responders. Some interesting differences were noted in the responses of the Swedish pilots compared with the U.S. and German pilots (see Table 2.2). On the average, Swedish pilots valued airframe agility (capability to pull +12 Gz and -Gz) less. This could be due to several factors including (1) lower average flying experience (flying hours) in the Swedish pilots interviewed, (2) the Swedish pilots included mainly operational pilots rather than test pilots or (3) national differences.

In summary, the pilots surveyed viewed the capabilities afforded by agile aircraft as useful for combat. The following sections provide additional detail from the questionnaire data and debriefing comments that specifically pertains to human factors issues, including physiologic problems, the pilot-vehicle interface, selection, and training. The final section re-examines the pilots' view of agile flight.

Table 2.1 Summary of Pilot Ratings of Agile Aircraft Capabilities

| Aircraft Capability | Average Rating | Range of Ratings | Number of Responses |
|-----------------------------|----------------|------------------|---------------------|
| Helmet mounted sight | 6.6 | 5-7 | 8 |
| High AOA/nose pointing | 6.2 | 1-7 | 35 |
| +12 Gz | 5.7 | 3-7 | 34 |
| Negative Gz | 3.2 | 1-7 | 34 |
| Combat Edge | 5.7 | 3-7 | 24 |
| Adv. Technology Anti-G Suit | 5.0 | 3-7 | 14 |

Table 2.2 Comparison of Pilot Ratings for Three Countries

| Aircraft Capability | U.S. | Sweden | Germany |
|------------------------|------|--------------|---------|
| Helmet mounted sight | 6.5 | No responses | 7.0 |
| High AOA/nose pointing | 6.2 | 4.8 | 6.7 |
| +12 Gz | 6.0 | 4.9 | 6.7 |
| Negative Gz | 3.7 | 2.1 | 3.3 |

2.2 PHYSIOLOGIC PROBLEMS

High AOA Flight: X-31 pilots described high AOA flight as feeling “unnatural” or “bizarre” at first, but they quickly adapted and denied any adverse physiologic sensations.

Acceleration Exposures: In the X-31, the +Gz exposure was generally limited to a brief +6 Gz pulse that decreased rapidly as airspeed decreased. X-31 pilots also experienced little negative Gs and almost no +/-Gy (side-slip).

Active Control of Aircraft: Pilots not in active control of the aircraft also related some adverse physiologic sensations. For example, Swedish pilots related some motion sickness symptoms related to automatic guns aiming.

+12 Gz: Pilots recognize that the G induced loss of consciousness (GLOC) problem has not yet been solved. Pilot predictions concerning the physiologic problems likely at +12 Gz also included discomfort, loss of situational awareness/disorientation, fatigue, degraded vision, decreased mobility, complaints about “cumbersome” equipment and concern about back/neck injury.

-Gz: The use of negative G’s was controversial. Many of the test pilots saw definite operational applications of negative G flight. Comments included “Need to be trained to think of using negative Gs. Could be a life

saver.” Other pilots, including many of the operational pilots, did not see a need for negative G maneuvering: “I do not need negative Gs.” “I do not use it”.

We were impressed however, at the interviewed pilots’ high level of negative Gs that had been experienced at sometime in their career. Listed below are the maximum negative Gs the pilots reported experiencing during several categories of maneuvers:

| | |
|--------------------------------------|-------------------|
| <i>Collision Avoidance:</i> | 4.8, 3.0, 2.3, 2 |
| <i>Acrobatics, Spin test, “Fun”:</i> | 3.2, 3.0, 3.0, -- |
| <i>Structural load testing:</i> | 3.2, -- -- -- |
| <i>Guns jink, missile avoidance:</i> | 3.0 2.0, 1.6, -- |
| <i>Lantirn bunt:</i> | 2.7, -- -- -- |

Thus, many of experienced pilots had actually experienced quite high levels of negative Gs. Pilot complaints concerning the physiologic problems at negative Gs included “Big time discomfort”, red out, loss of situational awareness/disorientation, and an inability to “remain in the seat.”

2.3 PILOT-VEHICLE ISSUES

Psychological Challenges: Psychological challenges to pilots included faster information flow. Pilots thought that the requirement to think ahead would become more urgent in agile aircraft due to the shorter time domain. Pilots predict that anticipation will become more difficult as aircraft agility increases.

2.3.1 Displays:

Head-up-Display: the HUD is "not useful when you're looking over your shoulder" – a helmet mounted display is needed.

Helmet-mounted Display (HMD): Pilots were enthusiastic in endorsing the requirement for HMDs, but requested that "clutter" on the display be kept to a minimum. "Vision is the most valuable sensor and should not be used for housekeeping."

Pilots were unanimous in demanding good visibility through the HMD – no "eye patch over one eye."

Test pilots felt that they were unable to adequately evaluate HMDs during short test programs. Like the HUD, pilots estimated that a HMD takes approximately 50 hours to get used to: "At first I never saw it."

Various possibilities for alternative displays were discussed with the test pilots that we interviewed. The pilots had mixed opinions on tactile and auditory displays. Positive comments were noted concerning three-dimensional auditory displays, although some stated that the pilot could easily ignore the aural tone. Others complained about too many "beeps" and "squeaks." The need for some additional cueing concerning aircraft energy state was the most frequently mentioned requirement anticipated by the pilots interviewed. Proprioceptive cues were mentioned as a possibility for use in cueing management. Requirements for cueing pilots on threats, ground proximity, fuel status, velocity vector, etc. were also noted. Cues need to be carefully chosen. For example, pilots said that for ground avoidance they would respond to a "break X", but might ignore more subtle cues (e.g., aural).

High AOA and Velocity Vector: One pilot related while descending into a scattered cloud bank at 11,000' he was "startled" by his rate of descent. Simultaneous display of nose position and velocity vector can be problematic (e.g. at AOA of 70 degrees). "The velocity vector between your feet can be a real problem."

Management of Energy State: Several pilots also commented that it was "Easy to command high AOA when you really do not want it." The X-31 was described as a "drag bucket." "No real sensation that you're coming down this fast (like a sky diver) ...need something that says that it is time to break off. Need some kind of cueing." Tactile cueing of high AOA state/post stall was incorporated into the X-31 for this reason. An improved method of conveying to the pilot his rate of descent was recommended.

Yaw Rates: Responses included comments concerning high yaw rates (guns tracking) and the need for wider horizontal field-of-view for the HUD.

2.3.2 Controls:

Integrated Flight Control System (IFCS): Pilots were also asked about "lessons learned" concerning high AOA flight. Many pilots commented on the importance of incorporating "Carefree Maneuvering" or integrated FCS into highly maneuverable/thrust vectored aircraft. Virtually all of the X-31 pilots commented that the integrated flight controls were very easy to learn – "Easy but radically different", "a dream for a test pilot," "Make it carefree then it allows you to do other things." Felt unnatural, very unnatural immediately ... "but easy to learn."

Conventional Controls: The experienced pilots stated that hands-on-throttle-and-stick concept (HOTAS), as it is, was not a limiting factor. Although the 50 functions on the control stick seemed formidable to the non-pilot, these experienced pilots did not feel that HOTAS represented a problem. Thus, the majority did not feel, based on their experience, that alternative controls were needed.

Alternative Controls: Pilots thought that current touch panel technology was not reliable enough; they called it "Fist on Glass" and suggested that it might be useful, for example, for an "on-off" function. For voice-based control, one pilot commented: "I can do it faster than I can say it." Pilots thought that current voice recognition technology was not reliable enough and worried about problems with surrounding auditory signals from anti-G straining maneuvers, oxygen breathing noises, etc.

Auto-GCAS: Regarding automatic systems for ground collision avoidance, pilots commented: "Nothing wrong with that." "Way of the future." "The Russians have done it for years." Pilots also saw a need for automated maneuvers in the future.

2.4 SELECTION, TRAINING, AND SIMULATION

The Harrier flight control system presents a high workload to the pilot. There is a consequent high risk of cognitive failure and a higher accident rate. Training for Harrier pilots takes 8 months compared to 4.5 months for other U.K. fighter pilots. Only those pilots who have performed well are selected for Harrier training.

This was in contrast to the X-31 Program with its integrated flight control system. The X-31 was "easy to learn", "not much training was needed", and "2-3 flights were sufficient" to get the most performance out

of the aircraft. Pilots state that simulation of the agile environment may not be adequate: "inadequate visuals, no motion"; however, they felt it "...good for switchology."

2.5 PILOT VIEW OF FUTURE REQUIREMENTS

Need for Agile Aircraft: Whether future pilots will be able to avoid close in combat in the future is of course a controversial question. Off-boresight capability, while a distinct combat advantage, was noted to be of offensive utility only. Avoiding close-in-combat was noted to depend on successfully acquiring, identifying (visual ID), and subsequently destroying 100% of the targets. This might not always be possible in small arenas, with rapid aircraft closure rates, and with limitations imposed by politics and rules of engagement. Opinion about super manoeuvrability: "Every capability that the others do not have is a capability. Any capability is one to be explored and you do not have to use it every time."

experience and the flight environment varied markedly from aircraft to aircraft. For example, the X-31 flight control system did not generate any side-slip and consequently X-31 pilots experienced minimal Gy accelerations. In the HARV, on the other hand, there was considerable side-slip. The HARV pilots commented that although it felt very unnatural, it was very controllable. In another example, the X-31 Program was characterized by only close in combat at speeds below 325 knots in the Mojave Desert with an IFCS. Thus, it may not be possible to generalize X-31 pilot responses to other scenarios.

During interviews, the pilots initially reported no adverse effects of high AOA maneuvering. X-31 pilots, for example, all stated that there were few adverse sensations experienced during agile flight regimes. On more detailed questioning, however, they related that although they experienced no adverse physiologic sensations when "flying in a clear sky", such sensations would be more likely in adverse weather conditions.

The aircrew commented on the many potential advantages conferred by vectored thrust including improved close in air combat kill ratio, short take off and landing capability (STO), efficiency with asymmetric loads, availability of the full envelope for collision avoidance ("Half the world is negative"), and the ability to make tailless aircraft with stealth and other advantages. The test pilots that we interviewed were convinced that the weight and cost penalties for adding vectored thrust capabilities were minimal.

2.6 LIMITATIONS OF PILOT SURVEY

One limitation was that the sample included only 37 highly experienced pilots. Also, there was a wide variation in the individual responses, especially for high AOA maneuvering and negative Gs. Pilots generally responded with regard to their particular flying