that the vehicle turns and descends more slowly during this phase in order to get onto the constraint boundary smoothly. As we expected, the trajectories stay on the constraint boundary when the flight is at the bottom of the trajectories. The vehicle maneuvers with high lift coefficient and large bank angle to obtain the maximum rate for turning. The maximum orbital plane-change angle for the heating-rate-constrained case with $v_f = 1.4$ is 8.5393 deg (23.0937 deg with $v_f = 1.0$), and for the unconstrained case it is 9.0851 deg (23.2636 deg). Hence, the penalty due to the constraint is 7.38% (0.74%). The normalized lift coefficient is discontinuous at s_1 and has a value 1.4474 at s_1^- and 1.4267 at s_1^+ for supercircular speed exit.

Conclusions

This paper presents the exact solution for the heating-rate-constrained optimal trajectory that maximizes the orbital plane-change angle by using the aerodynamic forces. With the variational formulation, a two-point boundary-value problem is formulated in which the constraint forms an interior boundary condition. The multiple shooting method and the continuation method are used for the numerical computation, and the modified Newton method is used to induce and accelerate convergence. The optimal trajectories with the initial entry speed corresponding to entry speed for a direct return from a geosynchronous Earth orbit and specified final exit speed are solved. From the results, it can be seen that the constrained trajectory has a large deviation from the unconstrained one. It stays much longer in the atmosphere, but the penetration into the atmosphere is more shallow. The trajectory enters the constraint boundary at a certain point of the descending arc and then leaves the boundary after a certain period of time when the vehicle is in its ascending arc. The vehicle performs pronounced maneuvers to obtain the maximum rate for turning during this period of time. For a shallow entry with 10% of speed depletion, the penalty on the orbital plane-change angle due to the heating-rate constraint is 7.38%.

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On the Level 2 Ratings of the Cooper-Harper Scale

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Introduction

THE acceptance and application of the Cooper-Harper flying qualities rating scale are universal. To attempt any "improvement," therefore, would appear to be folly. In their latest paper,[1] Cooper and Harper discuss potential problems with definitions in the level 2 region (see Fig. 1). As is stated in Ref. 1, in that region there "are adjectives to classify the severity of the deficiencies which warrant improvement. It is possible that the choice of one of these descriptors could conflict with the performance/compensation selections. This has not appeared to be a problem but, if it should be, the pilot should note the conflict and the reason for his final selection." This potential conflict between descriptors of performance and workload is also likely to yield different interpretations among different pilots. We might expect, therefore, more scatter in pilot ratings the more pilots are used, and especially if pilots of different backgrounds are used.

The potential conflict noted by Cooper and Harper was expected in a simulation performed in support of an aircraft development program with both performance and workload requirements. The environmental conditions specified for the landing performance meant that ratings in the 4–6 region were expected. In addition, evaluations were to be performed with pilots of different backgrounds. This author took the approach, therefore, of providing a more explicit definition of parts of the Cooper-Harper decision tree and rating descriptors. The intent is not to change any of the scale, but to amplify the definitions and remove ambiguities. The objective of this Note is to present these expanded definitions.

The Decision Tree

Figure 2 shows the decision tree with a different wording for the last decision. Cooper and Harper wrote, "Is it satisfactory without improvement?" This is equivalent to asking "Is desired performance attainable with a tolerable workload?" The latter wording is more consistent with the basic theme of assessing workload and performance; it is also believed to be less ambiguous for the non-test-pilot. The line pilot is more usually faced with flying an aircraft that is "satisfactory" by definition, whatever the flying qualities.

Note that the suggested wording does not change the level 1 ratings. It does, however, allow cleaner bounds on the different levels to be inferred. Level 1 means that desired performance can be achieved with acceptable workload. Level 2 means that desired performance can be achieved but workload is unacceptable. Also, adequate performance can be attained with acceptable workload. Level 3 means that desired performance cannot be achieved, and adequate performance may be achieved but workload is unacceptable. Thus, there is a more explicit consideration of both desired and adequate performance in the level 2 and 3 ratings, rather than an indistinct transition from desired to adequate performance.

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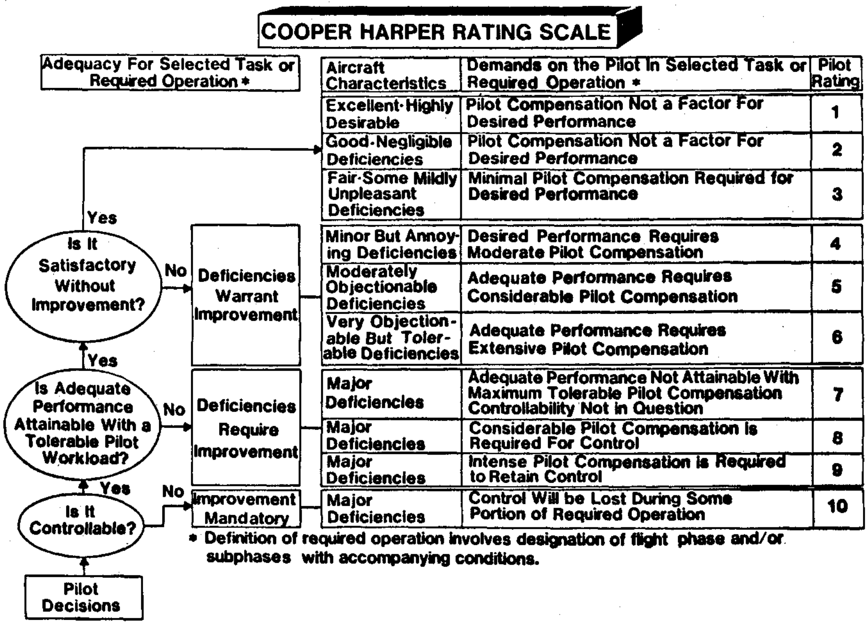

Fig. 1 Cooper–Harper pilot opinion rating scale.

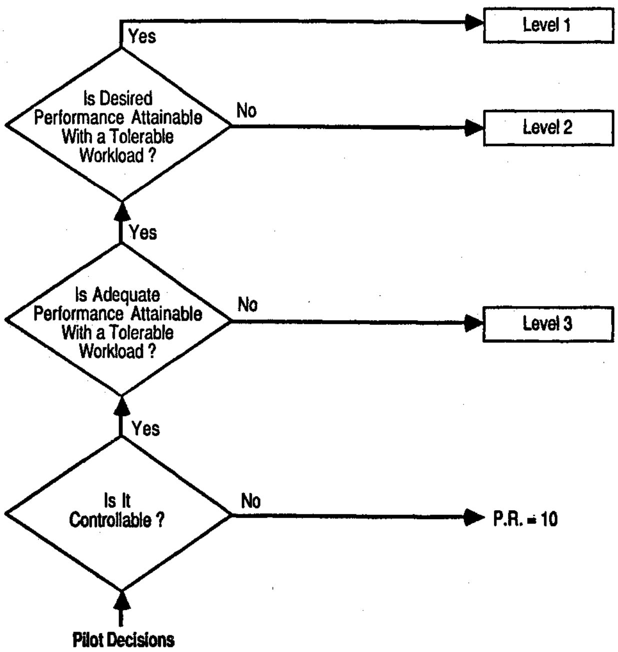

Fig. 2 Proposed decision tree.

Ratings Definitions

Figure 3 shows the suggested definitions of the individual ratings that are intended to support the preceding discussion. The level 1 definitions are largely unchanged; compensation is described as "tolerable" for a rating of 3. It should be kept in mind that this also includes maximum acceptable workload.

The level 2 definitions are completely new to give the degradations in workload for both desired and adequate performance. The spread from a rating of 4–6 for desired performance goes from moderate (just unacceptable) to maximum pilot compensation. Desired performance can be achieved, but the workload is considered too high for regular operation. Alternatively, the pilot can achieve relaxed performance standards with acceptable workload. The spread from a rating of 4–6 goes from minimal to maximum tolerable (acceptable) compensation. Adequate performance would be considered routine.

The level 3 definitions are changed slightly. Desired performance is not attainable: This appears explicitly in the definition for a rating of 7 and is understood for the others. In terms of adequate performance, the spread from a rating of 7–9 goes from attainable with unacceptable compensation to unattainable. Level 3 also includes the same consideration of controllability as in the Cooper-Harper definitions.

Experimental Setup

All the narrative in Ref. 1 is necessary for a successful experiment. The suggestions contained here imply one more consideration: The definitions of desired and adequate performance

Rating		
1	Pilot Compensation not a Factor for Desired Performance	
2	Pilot Compensation not a Factor for Desired Performance	
3	Pilot Compensation Required for Desired Performance is Tolerable	
4	Desired Performance Requires Moderate Pilot Compensation	Minimal Pilot Compensation Required for Adequate Performance
5	Desired Performance Requires Extensive Pilot Compensation	Adequate Performance Requires Some Pilot Compensation
6	Desired Performance May be Attainable with Maximum Pilot Compensation	Adequate Performance Requires Maximum Tolerable Pilot Compensation
7	Desired Performance not Attainable. Adequate Performance Requires Unacceptable Pilot Compensation. Control not in Question	
8	Adequate Performance Questionable. Considerable Pilot Compensation Required for Control	
9	Intense Pilot Compensation is Required to Retain Control. Adequate Performance Unattainable	
10	Control will be Lost	

Fig. 3 Proposed rating definitions.

must be consistent with the foregoing philosophy. The aforementioned definitions were attempted in a simulation with both landing and up-and-away tasks. For the landing task, adequate performance was simply defined as staying within the confines of the 1500- × 50-ft landing strip. Desired performance was defined as touching down in a marked area that extended 60 ft from the start of the landing strip and 10 ft on either side of the centerline. The up-and-away task was to track a target that was performing at different load factors. For this task, desired performance was defined as keeping a point on the target within a 5 mil pipper, whereas adequate performance was within a 10 mil pipper.

The simulations described were performed with a group of pilots comprising one contractor test pilot, two Air Force Test Center test pilots, and one NASA research pilot. All of the pilots were briefed according to the foregoing discussion. The Cooper-Harper decision tree and rating scale (Fig. 1) were to be used first. Figures 2 and 3 were to be used as aids in choosing a rating if there was any uncertainty. One Air Force test pilot used the additional figures explicitly a number of times to arrive at his rating. The other three pilots did not use the additional figures explicitly, but they also did not object to them. It is possible, however, that the presimulation meetings helped to remove any ambiguity in interpreting the basic Cooper-Harper scale. At least, the proposed additions formed an excellent tool for communication between the engineers and pilots on the objectives and intent of the simulation.

Conclusions

The Cooper-Harper rating scale is the universal tool for defining a pilot's subjective assessment of aircraft flying qualities. There is potential ambiguity in the definitions for level 2 ratings. Wording has been proposed to augment the Cooper-Harper scale and aid in assigning ratings in the level 2 region. It is also suggested as a help in communication between the engineers and pilots that will minimize variability in ratings due to pilots of different background.

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