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民机机身下部结构耐撞性优化设计

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Crashworthiness Optimization of Civil Aircraft Subfloor Structure

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摘要 针对含多设计参数的典型民机机身下部结构耐撞性设计,提出了一种设计方法,该方法以最小化客舱地板的初始加速度峰值与最大化参考压溃状态的结构内能为优化双目标,通过Kriging模型对结构的冲击响应进行预测,采用非支配排序遗传算法II(NSGA-II)对双目标进行优化,进而由Nash-Pareto策略获得最优方案。为了得到最优设计方案,同时研究设计参数对机身结构耐撞性的影响,提出最大化期望提高与最大化预测方差同步加点准则建立代理模型。采用该设计方法,以典型民机机身下部结构设计问题为算例,对客舱地板支撑结构、货舱地板和泡沫构件形状参数进行优化。结果表明,相对原始设计客舱地板的加速度峰值降低约18.3%,次高加速度峰值也得到有效降低,改善了机身结构的耐撞性;Kriging模型预测响应与有限元分析结果误差小于1%,说明了设计方法的有效性。

关键词: 耐撞性 机身 优化 Kriging模型 非支配排序遗传算法II Nash-Pareto策略

Abstract: For a typical civil aircraft fuselage structural crashworthiness design with several design parameters, a design approach is proposed to minimize the peak acceleration of the cabin floor and maximize the internal energy of the structure at a certain crushing state. A Kriging surrogate model is adopted for impact response approximation, a nondominated sorting genetic algorithm II (NSGA-II) for dual objective optimization, and Nash-Pareto strategy for the optimum design selection. In order to obtain the effect of design parameters on crashworthiness as well as the optimum design, a synchronous sampling criterion of the maximum expected improvement and the maximum predicted variance is suggested to construct a surrogate model. Using this design approach, a typical civil aircraft fuselage structural design with the shape parameters of the cabin floor struts, cargo floor and foam components is studied as a design case. The results indicate that the peak acceleration of the cabin floor is reduced by about 18.3% as compared with the original design; the second-highest peak acceleration is also reduced. Consequently, the crashworthiness of the fuselage structure is improved. The error between the predicted responses of Kriging model and the analysis results of the finite element method is less than 1%, which illustrates the effectiveness of this design approach.

Keywords: crashworthiness fuselage optimization Kriging model nondominated sorting genetic algorithm II Nash-Pareto strategy

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